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A Life-Cycle Inventory-Based Comparison of an RDX-Based and a TNAZ-Based GBU-24 Munition

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The primary goals of this project were to develop and demonstrate the use of LCAas a ,eams of comparing alternative PEP materials. A secondary goal was to produce an LCI for both the RDX-based and TNAZ-based munitions so that further work on improving the environmental footprint might take place.

In summary, based on a "less is best" comparison across the broad range of comparators, such as amount of listed (Federally regulated) waste or total energy consumption, the RDX-system appears to currently offer the least environmental dis-benefits. If some qualitative adjustments are made in the LCI to account for data quality, the RDX-based GBU-24 is still less environmentally harmful, but the gap between the systems is closed.

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ABSTRACT

U.S. Department of Defense (DoD) policy has elevated environmental considerations to an equivalent level of importance with cost and performance. Thus, with sponsorship from the Strategic Environmental Research and Development Program (SERDP), the DoD, U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) have cooperated in a program to develop technologies for clean production of propellants, energetics, and pyrotechnic (PEP) materials. Since the PEP program framework is strongly oriented around life-cycle assessment (LCA), a baseline life cycle inventory (LCI) of the guided bomb unit-24 (GBU-24) made with RDX explosives was conducted prior to this study in order to demonstrate the LCA approach.

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The authors acknowledge the use of life-cycle inventory data collected under the SERDP Program in the form of reports by J.K. Ostic and others from Los Alamos National Laboratory and L. Brown from Holston Army Ammunition Plant.

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Acronyms and Abbreviations

AHP	Analytical Hierarchy Process
AIRS	Aerometric Information Retrieval System
AIRS EXEC	AIRS Executive
AP	Acidification potential ("acid rain")
BCF	bio-concentration factor
BOD	biochemical oxygen demand
CAA	Clean Air Act
CIS	Chemical Information Systems
COCO	contractor-owned/contractor-operated
COD	chemical oxygen demand
CWA	Clean Water Act
DoD	Department of Defense
DOE	Department of Energy
EC	Expert Choice™
EIA	DOE's Energy Information Administration
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
GBU-24	Guided Bomb Unit (Earth penetrator bomb; Navy version is B/B)
GOCO	government-owned/contractor-operated
GWP	global warming potential
HAP	hazardous air pollutant
HSAAP	Holston Army Ammunition Plant
HV	hazard value
IARC	International Agency for Research on Cancer
IPPD	integrate product and process development
ISO	International Organization of Standards
LCA	life-cycle assessment
LCI	life-cycle inventory
LCIA	life-cycle impact assessment
LCImA	life-cycle improvements assessment
MCAAP	McAlester Army Ammunition Plant
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NSWC	Naval Surface Warfare Center
ODP	Ozone Depletion potential
PCB	polychlorinated biphenals
PCS	permit compliance system
PEP	propellants, energetics, and pyrotechnics
PM10	particulate <10 microns aerodynamic diameter
POCP	photochemical oxidant creation potential ("smog")
QSAR	quantitative structure activity relationship
RCRA	Resource Conservation and Recovery Act

R&D	research and development
RDX	trimethylenetrinitramine explosive
SAR	structure activity relationship
SETAC	Society of Environmental Toxicology and Chemistry
SERDP	Strategic Environmental Research and Development Program
TDS	total dissolved solids
TPY	tons per year
TRI	toxic release inventory
TSCA	Toxic Substance Control Act
TSS	total suspended solids
VOC	volatile organic compound
WOE	weight-of-evidence

1.0 Introduction

While the greening of weaponry may seem contradictory, it is not. Much of the weaponry prepared for the U.S. Department of Defense (DoD), especially larger items, is never consumed in the act of warfare, but is only a deterrent. As long as it remains a deterrent, preparing, maintaining, and disposing of (old or out-of-date) weaponry are acts through which humans and the environment interact with the weaponry and the resulting input or output streams. These activities, or the resulting emissions and consumption, are an argument for the greening of weaponry. In fact, current DoD policy has elevated environmental considerations to an equivalent level of importance with cost and performance (Perry, 1994).

The Strategic Environmental Research and Development Program (SERDP) is a cooperative effort between the DOD and the Department of Energy (DOE) to investigate Clean Agile Manufacturing of Propellants, Explosives, and Pyrotechnics. Coupled with DoD policy initiatives (outlined in 1994 by then Secretary Perry), the SERDP activity seeks to investigate and develop new and improved materials and processes that are intended to provide pollution prevention benefits of 50 percent to 90 percent reduction in Federally-regulated wastes. Within the diagnostic and analytical component of this effort, several evaluative tools and techniques are being evaluated, adapted for use in the DoD setting, and eventually exported to the weapons system design and development teams for application as routine procedures in system acquisition.

With these goals in mind and in cooperation with the US EPA through the Life Cycle Engineering and Design Project, SERDP set out to investigate the usefulness of life cycle assessment (LCA) methods to assess the greenness of a weapon system through a demonstration project. The goals of this study are two-fold. One, the application of LCA to provide a key part of the information basis for improvements is to be demonstrated. Two, the general approach to life-cycle improvement assessment, as adapted to DoD applications, is to be developed and ultimately disseminated to the users. The munition chosen for the study was the GBU-24 Earth-Penetrating Bomb. Reasons for choosing this munition include: 1) substitutes for the RDX-based explosive core are currently being investigated; trinitroazetidine (TNAZ) is one compound being considered, 2) other complementary manufacturing improvements are under development, and 3) Los Alamos National Laboratory has previously prepared an extensive systems model of the manufacturing operations and environmental profile for the RDX-based GBU-24.

Life Cycle Assessment (LCA) is a holistic method for examining the impact of a product or process on the environment. In an LCA the act of producing or processing is linked mathematically with activities occurring upstream (prior to the process of interest) and downstream (after the product of interest). These mathematical links allow the analyst to relate the contribution of the product or process, as well as each upstream or downstream contributing or supporting process, to the net system emissions or consumption resulting from the act of producing and using a product or process. The International Standards Organization (ISO) has developed two standards governing LCA. Standard 14040 describes the general principles and framework of LCA and Standard 14041 provides more detailed information on goal and scope definition and inventory analysis.

An LCA typically consists of several distinct phases. The first phase is Goals, Scope, and Boundary Definition. Here the purpose(s), objective(s), or question(s) to be answered through conduct of the LCA are defined, as is the extent of the system to be modeled — what processes are or are not intended to be included, i.e., the system boundary. According to the ISO standard, in defining the scope, the following items shall be considered and clearly described:

- Function
- Systems to be studied
- Allocation procedures
- Assumptions
- Initial data quality requirements
- Type and format of study report
- Functional unit
- System boundaries

- Data requirements
- Limitations
- Type of critical review (if any).

The second phase is the Life Cycle Inventory (LCI), which is the tabulation of the emissions and consumption associated with a product or process. Life Cycle Impact Assessment (LCIA) is the third phase. Here emissions or consumption terms are linked to environmental problems such as Global Warming Potential, Resource Depletion, or Human Health. The final phase is Interpretation. During this phase, the systems data are analyzed to determine which materials and processes contribute most to the results and to identify aspects in which the baseline and alternative systems are or are not discernibly different. These phases are interrelated and iterative. Life Cycle Improvements Assessment (LCImA) is but one of a number of uses to which the interpretation might be directed. Here the results of the LCI and LCIA are interpreted and qualitative evaluations of potential environmental improvements are identified.

For this improvement assessment, only the the LCI stage was conducted. These activities were conducted in accord with the U.S. EPA technical guidance manual (1993) for LCI studies. A parallel study (U.S. EPA, 1997b) on the life cycle impacts associated with the RDX-based GBU-24 system was used as a reference in estimating the impacts associated with the TNAZ-based GBU-24. The inventory data for the RDX-based GBU-24 are identical for each study.

2.0 Goals, Scope and Boundary Definition

Goal Definition

During the period 1993-95 the baseline resource use and pollution burdens for the life cycle of the GBU 24 B/B earth penetrator bomb unit were examined using a combination of primary data collected from the production sites and secondary-modeled data and literature information for commercial operations such as steel and ammonia production. This study was conducted by the Los Alamos National Laboratory. This information showed certain pollutional characteristics associated with both the batch production of the RDX and aluminum fill used in the GBU24 and the environmental burdens associated with on-site– and off-site–produced electricity and steam. Several alternative materials and processes are in various stages of development and could function as either replacement components, alternative processing technologies, or substitute materials.

The goal of this life cycle inventory study is to compare one such alternative energetic material, trinitroazetidine (TNAZ), with the baseline RDX (royal demolition explosive) energetic material. Although the primary implementation of this goal involved the development of data modules pertaining to TNAZ production, certain other changes, necessitated by the different physical and chemical properties of TNAZ, were required to be introduced into the baseline. These other differences are summarized below and discussed in greater detail further in the body of the inventory report.

TNAZ, like RDX, is compounded into the explosive mix and fill material (CXM7 and PBXN109 in the case of RDX) by blending it with other ingredients. It is likely that in actual production the blend would be tailored to the specific characteristics of TNAZ. However, for purposes of this inventory, which was configured to allow examination of TNAZ as a "drop-in" replacement for RDX, the fill material selected was an 80:20 mixture of TNAZ and aluminum, identical to that used in the current GBU24.

Production of TNAZ uses very different starting materials than RDX. Hence, the upstream operations were characterized on the basis of commercial production activities and secondary data sources. Depending on the amounts produced, actual production may determine that certain of the precursors could be produced by government-owned, contractor-operated (GOCO) facilities. Such GOCO facilities could be located at the existing sites for production of RXD-based munitions or at a greenfield site.

- In the original baseline inventory, the time distribution of resource consumption and emissions was based on assumptions about the peacetime production rates and the expected operational obsolescence of the stockpile of GBU24. Since no logistics setting has been uniquely defined for the TNAZ-based item, it was assumed that the operational deployment activities would be performed similarly except for the actual steps in demilitarization efforts that are specific to the physical properties of TNAZ.

- TNAZ has never been produced on a commercial scale. Therefore, it is impossible to obtain resource use and emissions information from actual full-scale operations. Instead the data developed from smaller scale (1 kg to 1,000 kg) syntheses was scaled to approximately commercial engineering operations through use of process simulation and thermodynamic computation models to assess ancillary operational requirements.

- Due to data problems with a subcontractor, not all of the data detail specified in the preliminary goal definition and scoping were obtained. This necessitated the assumption that certain process energy requirements for a TNAZ-filled GBU would be identical to those for the current GBU. This is unlikely to be entirely the case; however, given the data deficiency no other pathway was available.

Scope Definition

The intended scope of this study is the inventory

analysis of TNAZ as a drop-in replacement energetic fill material for RDX in a GBU-type end item. The inventory covers the cradle-to-grave activities of the alternative system in a manner similar to that of the baseline inventory. Specifically omitted are wartime deployment and stockpile replenishment and shipboard readiness activities. Also, in keeping with the boundaries of the original inventory, the resource use and emissions from RD&D activities during system development were excluded. In fact, these activities, particularly laboratory scale syntheses using alternative chemistries, engineering scale up trials, and qualification testing all have the potential to be contributory to the life-cycle profile. However, in the interest of showing the current profile for an "as-deployed" end item, these early stage contributions were omitted. All other operations from initial raw materials manufacturing to ultimate demilitarization were included in the system boundaries.

This study was conceived as including only an inventory analysis. Although an equivalency-based life-cycle impact assessment has been produced for the RDX-based item, resources did not permit a parallel effort for the TNAZ case study. Therefore, data collection and associated quality goals were specified for an inventory analysis. No external, third party critical review was identified as needed for the study. However, peer review was provided by the sponsoring organizations directly (U.S. EPA) and indirectly (U.S. Army).

The report format was designed to communicate clearly with the intended users. As noted in the introduction, there are two groups of users within the acquisition team — the process and system designers and the weapons system program managers and supervisory staff. In the former group, it is most important to illustrate the details of which activity steps are contributory to the overall environmental burdens. In the latter group, it is important to have the ability to compare the two different fill alternatives with respect to DOD-controlled versus commercial sector activity and to distinguish wastes that "count" towards the pollution prevention reduction goal (i.e., are listed wastes in RCRA, the Clean Water Act, or other legislation from the total environmental burdens), e.g., carbon dioxide contributions to global warming. These latter wastes may be used to further express general improvements in the overall environmental profile, but do not address achievement of the stated P2 goal.

Boundary Definition

For each system, all activities from acquisition of raw materials (geologic and biotic resources) through ultimate (peace-time) disposal were included. Excepted from the system were weapon system maintenance and/or preparatory activities, for example, periodic maintenance and calibration while deployed and any military use-readiness activities. Also excepted, as noted above, were research and development activities, and testing and deployment activities.

Primary materials common to both systems include iron ore, limestone, and coal for the bomb body and crude oil and natural gas as feedstocks for chemical synthesis or as fuels. Demilitarization was different for each system. Both systems also require salt and a source of nitrogen for use in upstream synthesis operations. The systems differ in the modes of acceptable demilitarization. Physical removal of the RDX followed by burning, to reduce volume, is the disposal method for RDX. Melt-out of TNAZ for recycle into other munitions is the method modeled. In each case, the bomb body is recycled via the scrap steel recycling infrastructure. Although it may be possible to reuse the bomb body with only minor refurbishment in the case of TNAZ, this operation was not modeled.

3.0 System and Inventory Module Descriptions

The GBU-24 is an earth penetrator bomb equipped with a laser guidance package designed to penetrate up to 6 feet of reinforced concrete. As shown in Figure 3-1, the assembled item consists of several component and subcomponent parts. The BLU-109 bomb body is the largest physical component and contributes the majority of the material mass to the system. The other components listed were not included because they are minor in comparison and are readily reused in any event. Within the BLU-109, the bomb case itself is the largest source of material (approximately 70 percent of the total weight) and efforts are underway to evaluate ways to reduce pollution from its manufacture through recycling of the steel. Approximately 27 percent of the total comes from the explosive fill. The PBXN-109 is a blend of four components: CXM-7 explosive mix, aluminum powder, thermoset plastic binder, and miscellaneous other blending and forming agents. About 3 percent of the mass is contributed by thermal insulation applied to the bomb exterior and asphalt interior liner.

The work flow representation of the RDX-based GBU-24 life cycle is illustrated in Figure 3-2. Raw materials are sourced for the energetic materials production from commercial commodity chemical producers. The synthesis of RDX, together with the coating and blending to manufacture CXM-7, is provided by Holston Army Ammunition Plant (HSAAP) in Kingston, TN. The CXM-7 is then shipped to McAlester Army Ammunition Plant (MCAAP) in McAlester, OK. Load/assemble/pack (L/A/P) operations are performed at MCAAP, which includes blending the CXM-7 with aluminum and other additives to produce the plastic-bonded explosive used for the GBU-24. The steel bomb bodies are also shipped to MCAAP from a commercial producer (National Forge).

For the TNAZ-based munition it was assumed that a similar arrangement would be maintained. Precursor materials to the explosives are purchased from various suppliers. Munition disassembly and explosive destruction or reclamation occurs at Indian Head Naval Surface Warfare Center (IHNSWC). Currently RDX is burned and the resulting ash disposed of in a landfill. One advantage of TNAZ is that it can be reclaimed and reused a number of times. The reclamation operation was also assumed to occur at Indian Head. Each system requires transport of materials or munitions, and consumes an amount of electricity generated off-site.

For the two systems, the L/A/P operations at McAlester were assumed to be almost identical in that TNAZ was assumed to be a true "drop-in" replacement for RDX. This is not exactly the case since TNAZ has a greater energy density and, thus, needs some additional filler to increase the mass and volume of TNAZ-based explosive material in the GBU-24 in order to maintain its flight characteristics.

One other point to consider is the state of development of each of the two systems. The RDX-based munition has been produced for a number of years, hence optimization of the system with regard to yield and energy efficiency is near maximum. The TNAZ-based system is still in the lab scale/pilot scale developmental stage. While much optimization has taken place (more than an order of magnitude reduction in total waste per pound of TNAZ produced was achieved between 1993 and 1996 alone), it is thought that more will occur, especially as the system is scaled up to production quantities. The TNAZ system modeled in this LCI is a hybrid of lab and/or pilot scale developments with some potential, and highly probable, modifications to increase yield or energy efficiency, or change the input resource to those thought to be cause less environmental harm.

RDX-Based System

A baseline inventory (LCI) of the current GBU-24 earth penetrator bomb was conducted during 1993 and 1994 (the data basis was 1992 operations). That effort attempted to adhere very closely to the LCI methodology described in Society of Environmental Toxicology and Chemistry (SETAC) and U.S. EPA technical guideline publications (U.S. EPA, 1993). Preliminary results of that analysis have been reported in several forums and publications (Ostic, 1994; Brown, 1995; Newman and Hardy, 1995) and are briefly

summarized below. Numerous organizations supplied information for the baseline effort including the following.

- Commercial Raw Materials Production, Fuels Acquisition, and Electric Power Generation: Battelle Columbus

- Intermediate/Fill Materials Production and L/A/P Operations: Holston and McAlester Army Ammunition Plants

- Use/Maintenance and Demil Operations: Naval Surface Warfare Center, and Coordination of Inventory Data Assembly: Engineering Systems Analysis Department, Los Alamos National Laboratory.

Assembly and validation of the data, together with the modeling of the system resource consumption and environmental burdens, was performed by the Technology Modeling and Analysis Group at LANL. The environmental emissions and energy and resource consumption output from this model was provided to Battelle.

Modeling of the GBU-specific manufacturing operations was performed in considerably greater detail than for the commercial sector activities. This was done for several reasons, not the least of which was the fact that the span of control of DoD for influencing such major industrial activities as steel and ammonia manufacture is limited. Table 1 illustrates the specific activities and process streams included in the LANL LCI model.

Battelle tabulated the inventory data provided by LANL in two dimensions. The first dimension was life cycle stage as Precursor production, HSAAP operations, MCAAP operations, IHNSWC operations, Transportation, Waste Management, and Electricity production, in order to relate emissions to the scope of control of the involved entities. The second dimension was regulatory status: Listed or Non-listed. Listed wastes are those explicitly mentioned in any of the following Federal environmental regulations, and are those to which the pollution prevention goals mentioned above are directed.

- Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA/Superfund)
- Toxic Substances Control Act (TOSCA)
- Clean Water Act (CWA)
- Clean Air Act and Amendments (CAAA)
- Superfund Amendments and Reauthorization Act (SARA)
- Toxics Release Inventory (TRI)
- Resource Conservation and Recovery Act (RCRA).

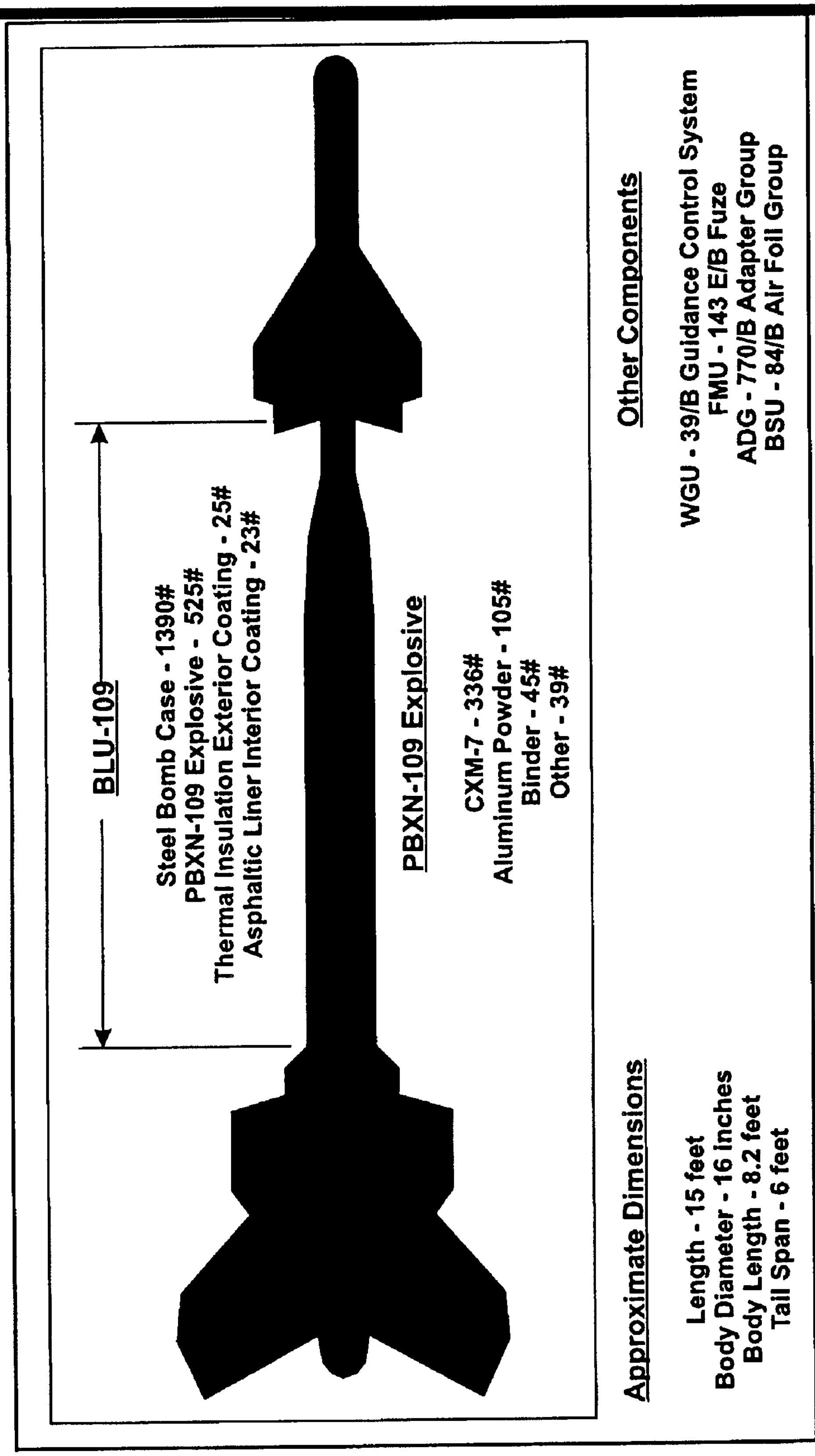

Figure 3-1. GBU-24: A conventional explosive earth penetrator (the functional unit for the LCA is the bomb body called BLU-109).

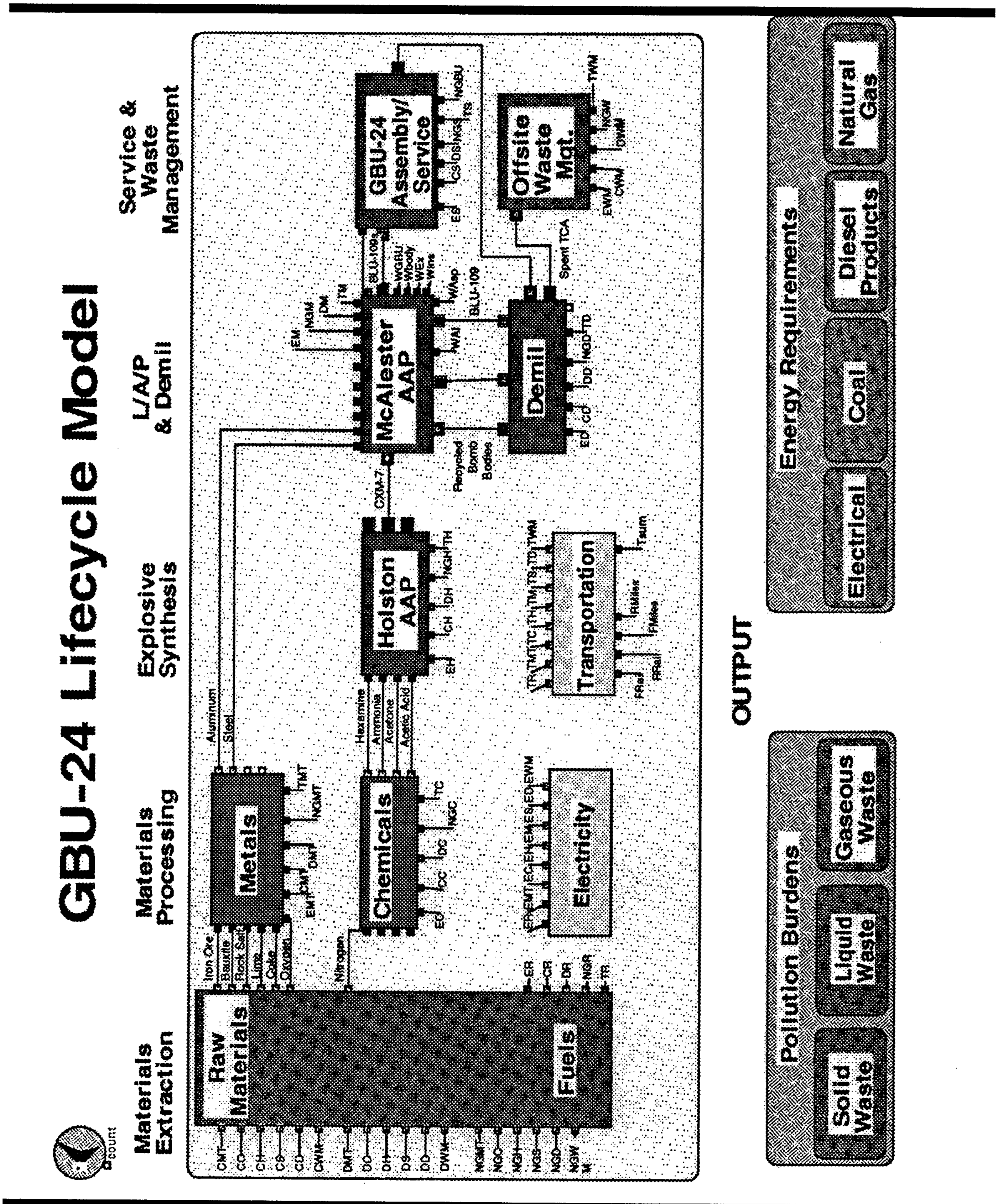

Figure 3-2. GBU-24 life cycle model.

Table 3-1. Summary of Data Included in LANL RDX-based GBU-24 Life Cycle Inventory

	Consumption		Emissions		
Process or Activity	**Resources**	**Energy**	**Air**	**Water**	**Solid Waste**
Geologic and Biotic Resource Extraction					
Bauxite	Included	Included	Included	Included	Included
Coal	Included	Included	Included	Included	Included
Iron Ore	Included	Included	Included	Included	Included
Limestone		Included			
Natural Gas	Included	Included	Included	Included	Included
Petroleum	Included	Included	Included	Included	Included
Intermediate Materials Manufacture					
Acetic Acid	Included	Included	Included	Included	
Acetone	Included	Included	Included	Included	Included
Aluminum	Included	Included	Included	Included	Included
Ammonia	Included	Included	Included	Included	
Coke		Included			
Cyclohexanone					
Dioctyl adipate (DOA)					
Formaldehyde	Included	Included	Included		
Hexamine	Included	Included			Included
Nitric acid	Included	Included	Included	Included	
Nitrogen		Included			
Oxygen		Included			
Propyl acetate					
Steel	Included	Included	Included		Included
Steel Forging	Included	Included			
Trichloroethane					
Triethyl phosphate					
Holsten AAP					
Acetic acid Production	Included	Included	Included	Included	Included
Acetic anhydride Concentration	Included	Included	Included	Included	Included
Area A Steam Plant	Included	Included	Included	Included	Included
Explosives Plant	Included	Included	Included	Included	Included
Nitric acid Production	Included	Included	Included	Included	
Spent acid Recovery	Included	Included	Included	Included	
Nitric acid Concentration	Included	Included	Included	Included	
Nitric acid - Ammonium nitrate Production	Included	Included	Included	Included	
Industrial Wastewater Treatment Plant	Included	Included		Included	Included
Filtered Water Production					
Burning Ground					
Incinerator					
McAlester AAP					
Inert Preparation	Included	Included	Included		Included
Receiving	Included	Included			
Mixing	Included	Included	Included		Included
Casting	Included	Included	Included	Included	Included
Bomb Seal	Included	Included		Included	Included
Final Assembly	Included	Included			
Radiography	Included	Included			
Chemical Laboratory	Included	Included	Included		Included
Boiler	Included	Included	Included		
Demilitarization					
Disassembly		Included			
Water Jet Washout	Included	Included		Included	Included
Solvent Soak	Included	Included		Included	Included
Burning Ground		Included	Included		Included
Water Treatment	Included				
Off-site Electricity Generation					
Coal-fired Plant	Included	Included	Included		Included
Diesel-fired Plant	Included	Included	Included		
Natural gas-fired Plant	Included	Included	Included		
National Grid	Included	Included	Included	Included	Included
Transportation					
Transportation	Included	Included	Included	Included	Included

TNAZ-based System

The approach to modeling the life cycle of the TNAZ-based munition was a straight-forward replacement of the appropriate processes and segments of the RDX-based system. No work had been done on modeling the TNAZ-based system, but the LANL computational framework and engine are modular so that appropriate TNAZ specific pieces could be substituted. Battelle undertook the generation of modules for precursors to TNAZ production, along with modules for demilitarization including recycling of TNAZ. This modeling effort entailed preparing process characterizations and mass balances for each needed module. Battelle subcontracted with LANL to integrate the new modules into the existing computational framework to make adjustments to the model for changes in operations and emissions at Holston and McAlester that would result upon the substitution of TNAZ into the GBU, and to provide results for a number of defined scenarios. The task of calculating process energy requirements and government-owned facility energy infrastructure changes necessary to support TNAZ manufacture and use was also subcontracted to LANL.

The modules prepared by Battelle included formaldehyde, NIB-glycerol, di-isopropylazodicarboxylate, triphenyl phosphine, acetic anhydride, tert-butylamine, sodium hydroxide, hydrochloric acid, hydrogen peroxide, isopropanol, 2-butanone (methyl ethyl ketone), sodium nitrite, potassium ferrocyanide, sodium persulfate, methyl tert-butyl ether, ferrous chloride, nitric acid, ammonium nitrate, ethanol, acetonitrile, nitrogen, deionized water, Dow 2210 antifoaming agent, and melt out of TNAZ from decommissioned munitions. Data for these modules was taken from the LANL work on RDX and from other LCIs. Some modules were developed from first principles of chemical engineering. A complete listing of calculations and data sources is given in Appendix D, while data sources and brief descriptions are given in Table 3-2.

Table 3-2. Summary of TNAZ-Based LCI Modules Prepared by Battelle

Module	Data Sources	Notes
Formaldehyde	Brown, Hamel and Hedman, 1985	Production of formaldehyde from methanol.
Methanol	Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1991; CRC Press, 1986	Engineering calculations for methanol production as part of acetic acid production.
Acetic acid	Lowenheim and Moran, 1975	Production of acetic acid from methanol.
Manufactured gas or Synthesis gas	Kirk-Othmer, 1964	Production of synthesis gas from coal.
Nitroethane	Kirk-Othmer, 1978; W.R. Grace Co., 1992	Co-production of nitro compounds: nitroethane, nitromethane, nitropropane, from nitrogen and light hydrocarbons.
Nitric acid and Ammonium nitrate	Holston Defense Corporation	Co-production of nitric acid and ammonium nitrate at Holston AAP.
Diisopropyldiazodicarboxylate	McGraw Hill, 1984; U.S. EPA, 1985; CRC Press, 1986.	Engineering calculations of emissions and energy and resource consumption from DIAD production.
Phosgene	Lowenstein and Moran, 1975; McGraw Hill, 1984; CRC Press, 1985; U. S. EPA, 1985; SRI, 1993	Engineering calculation of emissions and energy and resource consumption for phosgene production.
Ammonia	U.S. EPA, 1985; U.S. DOE, 1994; U.S. EPA, 1995; U.S. DOE, 1993	Production of fertilizer quality ammonia.
Sodium hydroxide	SimaPro 3.0, 1994	Co-production of sodium hydroxide, chlorine and hydrogen via electrolysis of brine.
Sulfuric acid	U.S. EPA, 1995; Fertilizer Institute, 1982	Production of sulfuric acid via the phosphate wet method.
Monochlorobenzene	Lowenheim and Moran, 1974; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1964; U.S. ITC, 1994	Engineering calculation of emissions and resource and energy consumption for monochlorobenzene production.
Benzene	SimaPro 3.0, 1994	European production of technical grade benzene.
Isopropanol	Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1985	Engineering calculation of emissions and resource and energy consumption from isopropanol production.
Propylene	SimaPro 3.0	European production of monomer quality propylene.
Phosphorus trichloride		Engineering calculations of emissions and energy and resource consumption for phosphorus trichloride production.
Acetic anhydride	Holston Defense Corporation	Production of acetic anhydride at Holston AAP.
Acetic acid	Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1964; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption for acetic acid production.
Methyl Ethyl Ketone	Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption for MEK production.
Butylene	SimaPro 3.0, 1994	European production of monomer quality butylene.

Module	Data Sources	Notes
Methyl tert-Butyl Ether	Lowenheim and Moran, 1975; Mc Graw Hill, 1985; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption during MTBE production.
Ethanol (via Fermentation from Corn Sugars)	Numerous	Production and harvesting of corn. Transportation of corn to processing center. Milling of corn to separate sugars and starches from fiber.
Acetonitrile	Lowenheim and Moran, 1975; Mc Graw Hill, 1985; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986	Engineering calculation of emissions and resource and energy consumption during co-production of aceto-nitrile and acrylonitrile.
Demilitarization		Engineering calculations of emissions and resource and energy consumption during demilitarization.

A number of assumptions were made for the TNAZ - based system LCI. First, energy consumption would be similar for both the RDX-based and TNAZ-based systems so that the RDX-based energy consumption information could be used in the TNAZ-based system LCI. Second, the transportation infrastructures for the two systems were identical. Given that manufacturing operations have not been sited for the processes this appears to be a reasonable approach. If direct reuse of the bomb body proves feasible then transportation emissions and energy consumption should decrease for the TNAZ-based GBU. The third assumption was that the electricity generation emissions were also identical in the two systems. In part, these assumptions were necessary to complete the LCI because LANL was not able to provide the results of the TNAZ-based modeling in sufficient detail to allow TNAZ-specific substitutions to be developed and incorporated into the LCI and verified.

4.0 Results

The detailed life cycle inventories are presented in Appendices A and B for the RDX-based and TNAZ-based systems, respectively. The following tables and figures summarize and compare the results presented in Appendices A and B. For most of the results presented in the tables the wastewater emitted during production of the TNAZ-based GBU-24 has been intentionally omitted. Since *no* wastewater emission is listed for the RDX-based system the description of the wastes for the two systems is more comparable when this omission from the RDX-based system emissions is compensated for by ignoring wastewater emissions from the TNAZ-based system. The result is a comparison of the mass of contamination of the wastewater.

Table 4-1 lists Total Emissions from each of the two systems. The amounts of listed and non-listed wastes are also given. For both Total Emissions and Listed Emissions the RDX-based munition has significantly lower emissions. There is no discernable difference among the systems for Non-Listed Emissions. The results are presented in Figure 4-1.

Table 4-1. Total Emissions from Systems (in pounds per GBU-24)

Emission	RDX-based GBU-24	TNAZ-based GBU-24
Listed	1,158	20,733
Non-Listed	30,837	29,547 (1)
Total	31,995	50,280

(1) Less wastewater discharge of 11,654,826 lb.

Emissions by environmental compartment also tend to favor the RDX-based system (see Table 4-2 and Figure 4-2). The exception being Air Emissions where no discernable difference exists between the systems.

Table 4-2. Emissions from Systems by Environmental Compartment (in pounds per GBU-24)

Compartment	RDX-based GBU-24	TNAZ-based GBU-24
Air Emissions	26,945	27,072
Water Emissions	354	9,176 (1)
Solid Wastes	4,697	14,033

(1) Less wastewater discharge of 11,654,826 lb.

Tables 4-3 and 4-4 and Figures 4-3 and 4-4 present the results for Listed and Non-Listed Emissions by point of origin. Emissions for Transportation, Waste Management, and Off-site Electricity Production were identical for the two systems since the RDX-based system data was used for the TNAZ-based system. The RDX-based system has lower emissions of Listed Wastes during Precursor Production and at Military Facilities. Non-Listed Wastes emitted from Military Facilities are lower for the TNAZ-based system.

Table 4-3. Listed Emissions for Each System by Point of Origin (in pounds per GBU-24)

Point of Origin	RDX-based GBU-24	TNAZ-based GBU-24(1)
Precursors Production	620	7,640
Military Facilities	364	12,919
Transportation	4	4
Waste Management	0	0
Off-site Electricity Production	169	169

(1) Less wastewater discharge of 11,654,826 lb.

Table 4-4. Non-Listed Emissions for Each System by Point of Origin (in pounds per GBU-24)

Point of Origin	RDX-based GBU-24	TNAZ-based GBU-24(1)
Precursors Production	6,332	6,291
Military Facilities	7,934	6,685
Transportation	189	189
Waste Management	773	773
Off-site Electricity Production	15,609	15,609

(1) Less wastewater discharge of 11,654,826 lb.

Resource consumption is also much less for the RDX-based GBU-24 (see Table 4-5 and Figure 4-5). Again, however, there was an obvious omission from the results for the RDX-based system in that there was *no* water consumption. For the TNAZ-based GBU-24 water consumption amounts to almost 2.5 million pounds. The

values in the table and figure include this water consumption. (Geologic and Biotic Resources are raw materials extracted from or grown on the earth or oceans. Intermediate Materials are refined products that have not been traced back to geologic or biotic materials. For example, crude oil is a geologic resource, while gasoline is an intermediate material.)

Table 4-5. Resource Consumption by Systems (in pounds per GBU-24)

Resource	RDX-based GBU-24	TNAZ-based GBU-24
Geologic and Biotic Resources	20,133	6,372,692[1]
Intermediate Materials	1,009	21,846

[1] Includes 2.5 million pounds of water consumed

Table 4-6 and Figure 4-6 illustrate the geologic and biotic resource consumption by stage. Figure 4-7 and Table 4-7 present the results for intermediate materials consumption. Again, data for Transportation, Waste Management, and Off-site Electricity Production are identical for the two systems. Differences in resource consumption are not discernable between the systems for any stage except for Precursor Production, where the RDX-based system is considerably lower. The RDX-based system is also lower for Intermediate Materials consumption for both Precursor Production and consumption at Military Facilities.

Table 4-6. Geologic and Biotic Resource Consumption by Stage (in lb per GBU-24)

Stage	RDX-based GBU-24	TNAZ-based GBU-24
Precursor Production	9,630	6,361,792
Military Facilities	4,178	4,575
Transportation	0	0
Waste Management	100	100
Off-site Electricity Generation	6,225	6,225

Table 4-7. Intermediate Materials Consumption by Stage(in lb per GBU-24)

Stage	RDX-based GBU-24	TNAZ-based GBU-24
Precursor Production	296	14,268
Military Facilities	713	7,578
Transportation	0	0
Waste Management	0	0
Off-site Electricity Generation	0	0

Energy consumption again is lower for the RDX-based GBU-24, by a wide margin (see Figure 10). Energy consumption (all energy sources considered) was 151 million Btus per GBU-24 for the RDX-based system and 1,954 million Btus per GBU-24 for the TNAZ-based system. For the RDX-based system it is 73.4 percent derived from coal and 19.8 percent derived from natural gas, with the balance being electricity or petroleum. Steam (fuel(s) unspecified) was the primary energy source for the TNAZ-based system at 88.4 percent. Nuclear energy (5.2 percent) and coal (3.8 percent) are the next biggest energy sources.

Table 4-8 and Figure 4-9 illustrate Energy consumption by stage. Again the same data were used for both systems for the Transportation, Waste Management, and Off-site Electricity Production stages. For the remaining stages, Precursor Production, and at Military Facilities, the RDX-based system consumes much less energy.

Table 4-8. Energy Consumption by Stage (in Mbtu per GBU-24)

Stage	RDX-based GBU-24	TNAZ-based GBU-24
Precursor Production	12	148
Military Facilities	61	1,728
Transportation	1	1
Waste Management	3	3
Off-site Electricity Production	73	73

Table 4-9 presents a summary of all of the comparisons made above. For each comparison, the system that was the most environmentally beneficial, judged as less is better, was indicated on the table with a '•'. A difference between the systems of 15 percent was used to judge which was better, i.e., the value for the TNAZ-based system had to be more than 15 percent higher or lower than the value for the RDX-based system in order for one of the systems to be judged better. If the values for the systems did not differ by more than 15 percent neither was judged to be better. The value of 15 percent was chosen based on the experience of the analyst. As a check on this choice a 10 percent margin was also used. The information in Table 4-9 does not change with a 10 percent margin. If the margin is changed to 20 percent, the outcome of one comparison changes. Instead of the TNAZ-based system being better for Non-Listed Military Facility Emissions, neither system is better.

The value chosen for the margin is a reflection of the perceived data quality. The higher the perceived quality of the data the lower the margin at which one believes comparable systems can be differentiated. Which is the

most correct value? Battelle recently completed a LCI on residential nylon carpet for the U.S. EPA (1997a) in which the propagation of error in an LCI was studied. What was found was that, for the carpet system, individual input parameters could be varied by as much as 20 percent with 95 percent of the output values varying by less than 13 percent. The TNAZ-based system LCI contains a large number of engineering estimates for emissions and consumption simply because the system has not been scaled up and operated at full scale to allow measurements. While these are engineering estimates, they are not likely to vary by more than 20 percent from the true values. Therefore, the output is expected to vary on the order of 15 percent, as it did for the carpet LCI, thus the choice of a 15 percent margin.

Table 4-9. Life Cycle Inventory Summary Comparison

Comparator	RDX-based GBU-24	TNAZ-based GBU-24
Total Emissions	•	
Listed Emissions	•	
Non-Listed Emissions		
Air Emissions		
Wastewater Emissions	•	
Solid Wastes	•	
Listed Emissions - Precursor Production	•	
Listed Emissions - Military Facilities	•	
Listed Emissions - Transportation		
Listed Emissions - Waste Management		
Listed Emissions - Off-site Electricity Production		
Non-Listed Emissions - Precursor Production		
Non-Listed Emissions - Military Facilities		•
Non-Listed Emissions - Transportation		
Non-Listed Emissions - Waste Management		
Non-Listed Emissions - Off-site Electricity Production		
Total Resource Consumption	•	
Geologic and Biotic Resources	•	
Intermediate Materials	•	
Geologic and Biotic Resources - Precursor Production	•	
Geologic and Biotic Resources - Military Facilities		
Geologic and Biotic Resources - Transportation		
Geologic and Biotic Resources - Waste Management		
Geologic and Biotic Resources - Off-site Electricity Generation		
Intermediate Materials - Precursor Production	•	
Intermediate Materials - Military Facilities	•	
Intermediate Materials - Transportation		
Intermediate Materials - Waste Management		
Intermediate Materials - Off-site Electricity Generation		
Total Energy Consumption	•	
Energy Consumption - Precursor Production	•	
Energy Consumption - Military Facilities	•	
Energy Consumption - Transportation		
Energy Consumption - Waste Management		
Energy Consumption - Off-site Electricity Generation		

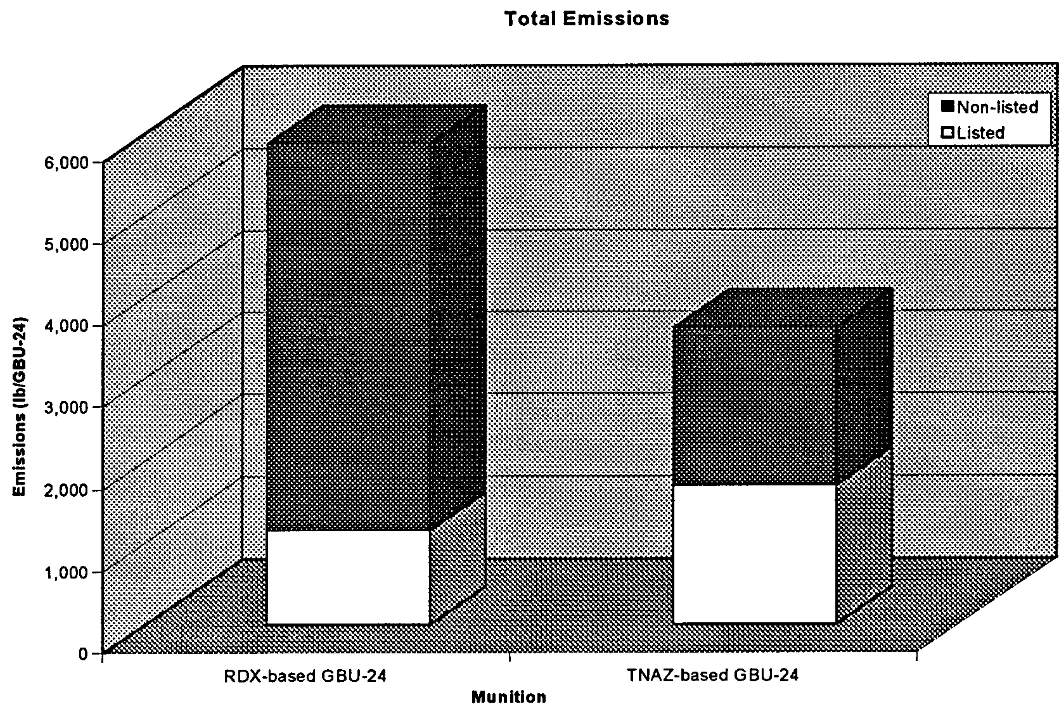

Figure 4-1. Total emissions.

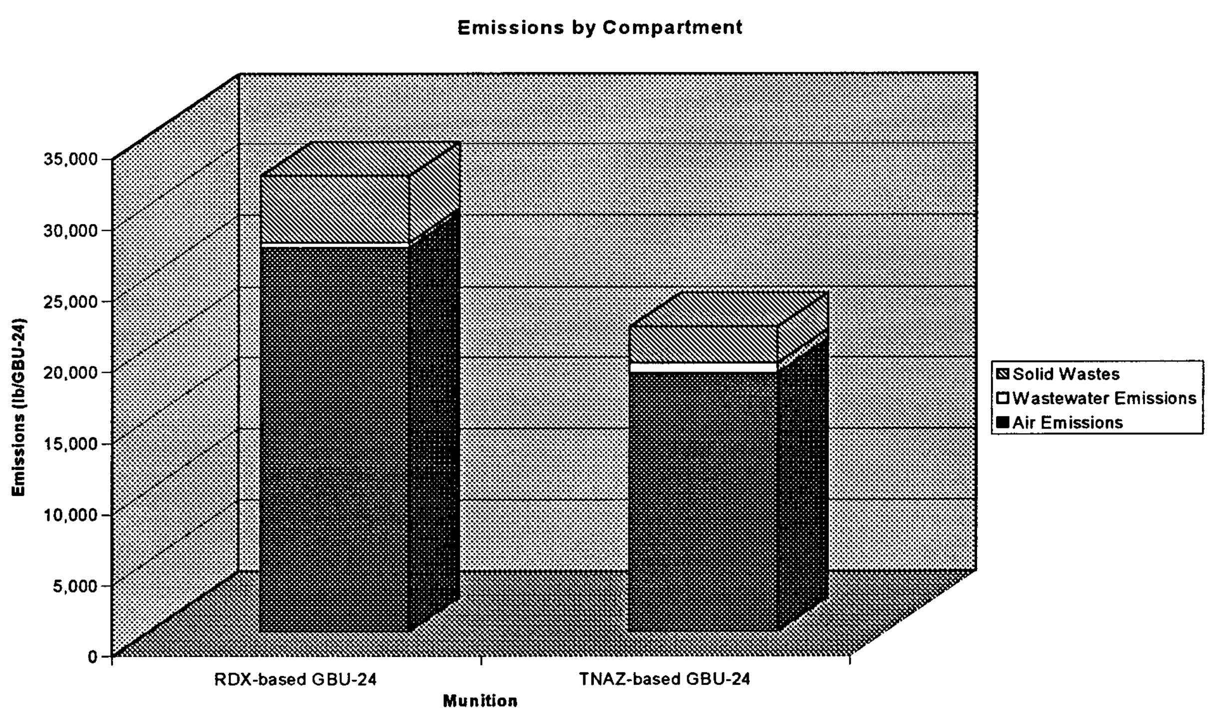

Figure 4-2. Emissions by compartment.

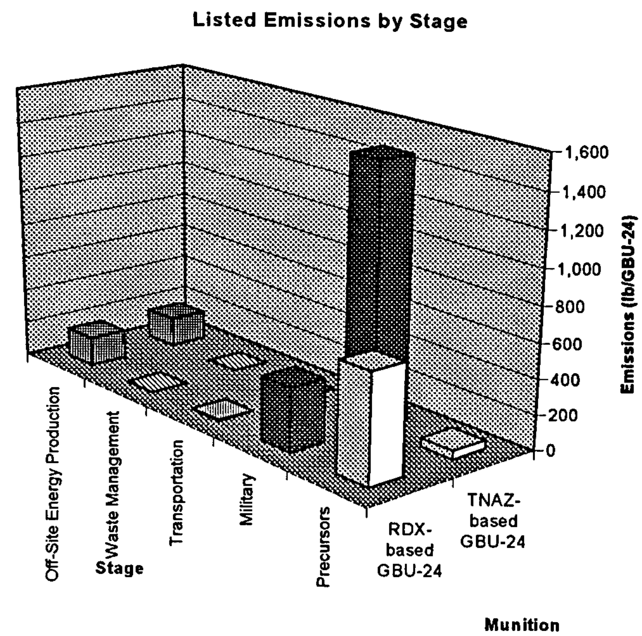

Figure 4-3. Listed emissions by stage.

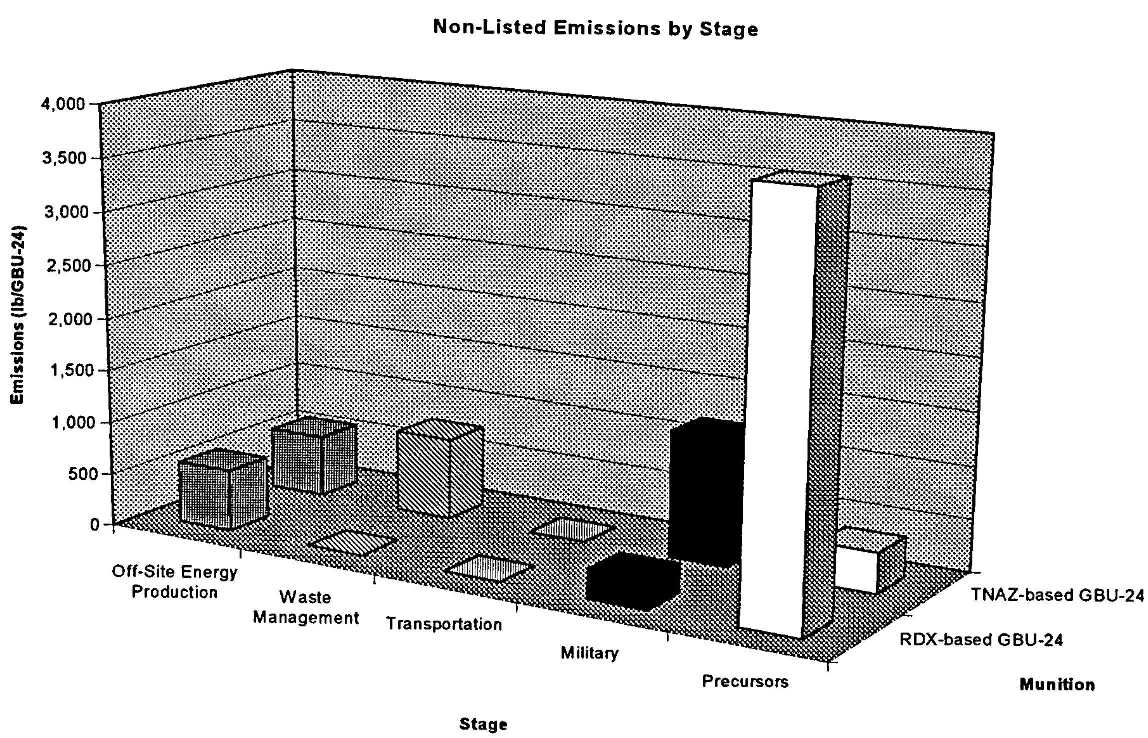

Figure 4-4. Non-Listed emissions by stage.

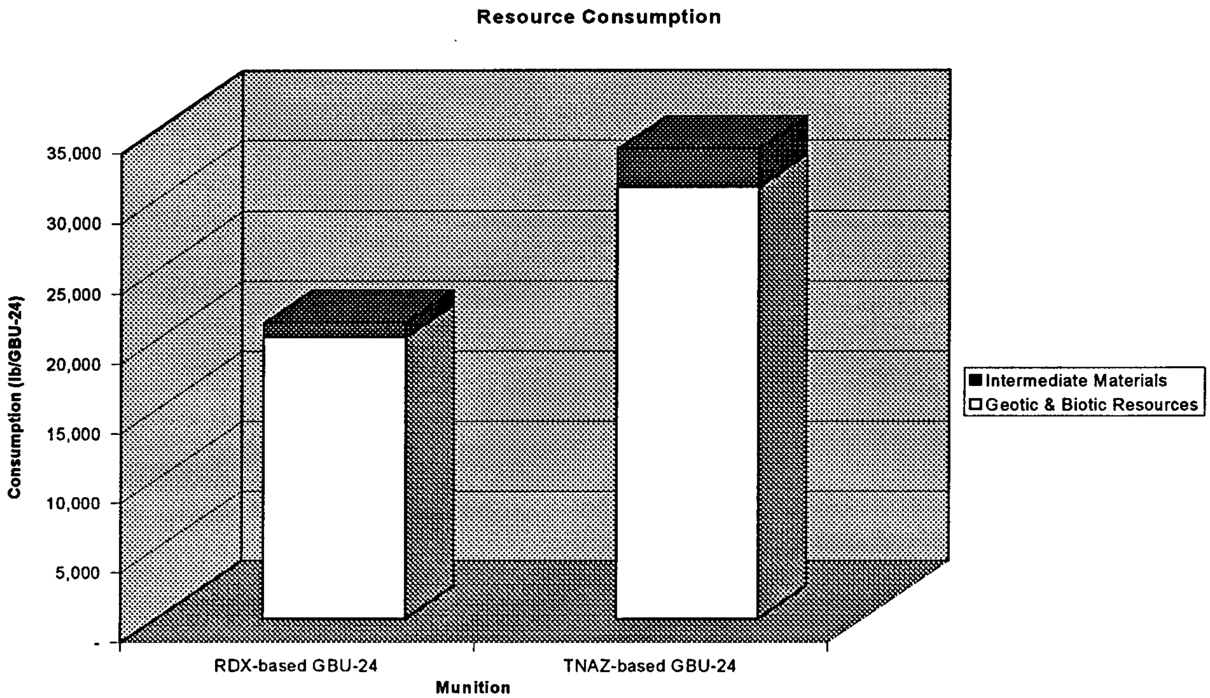

Figure 4-5. Resource consumption.

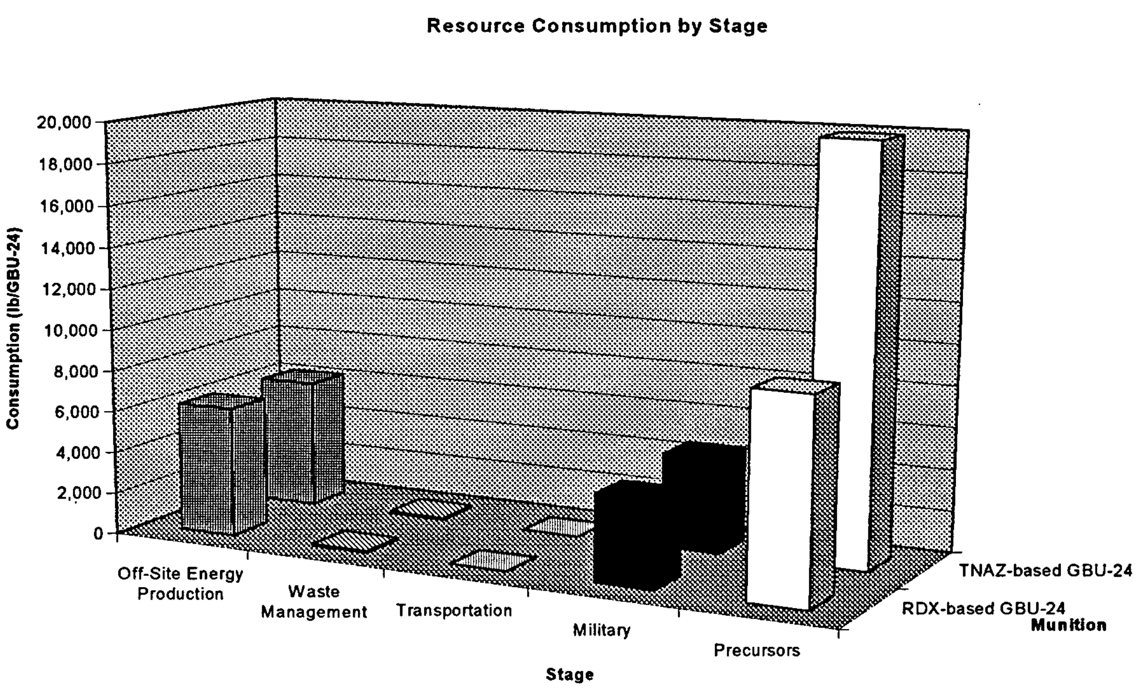

Figure 4-6. Resource consumption by stage.

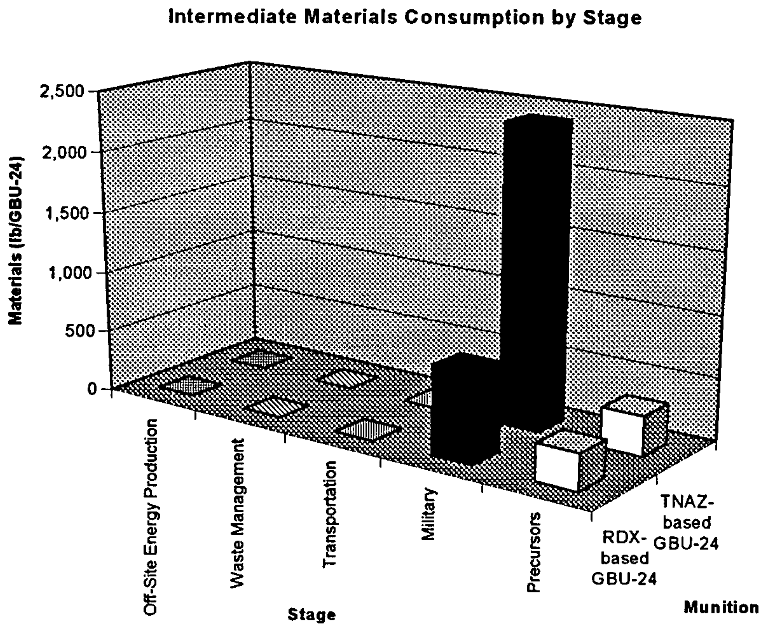

Figure 4-7. Intermediate materials consumption by stage.

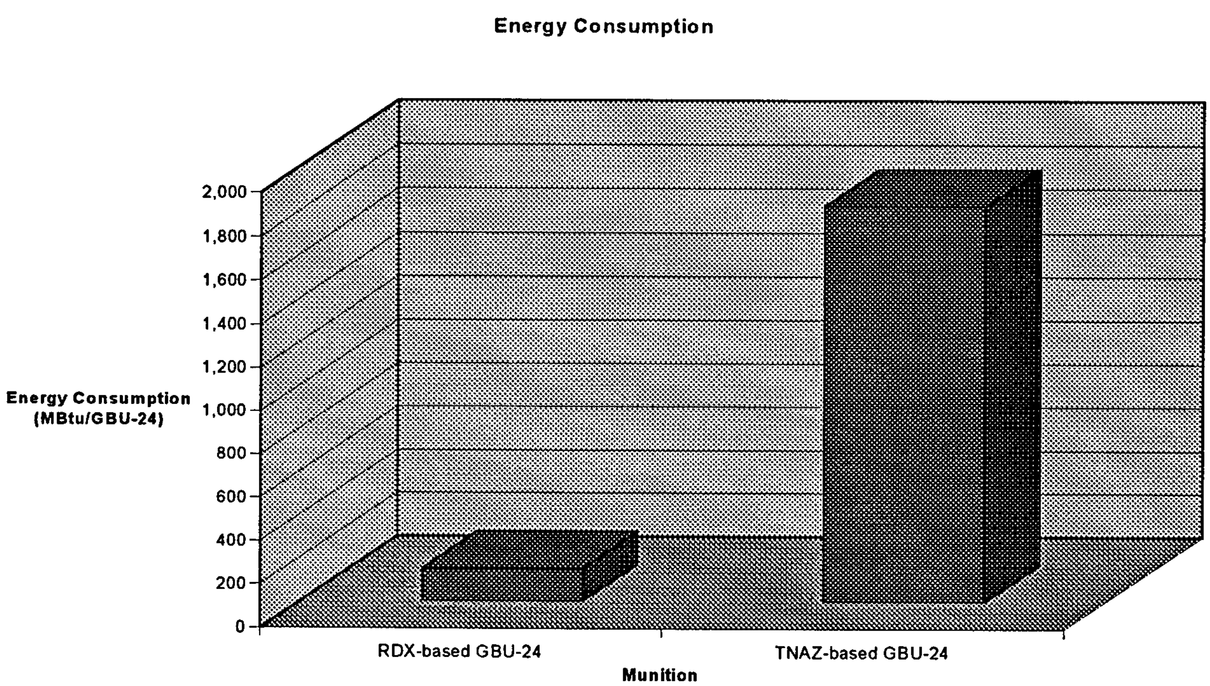

Figure 4-8. Energy consumption.

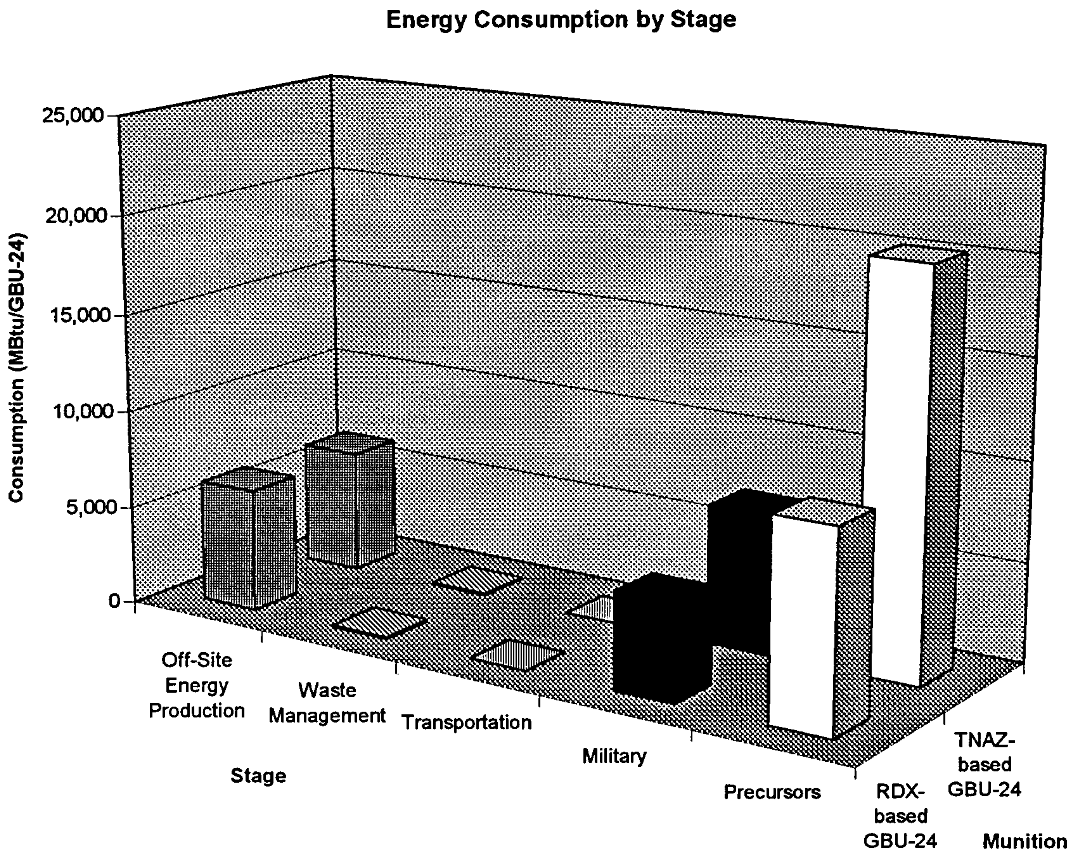

Figure 4-9. Energy consumption by stage.

5.0 Discussion

The RDX-based GBU-24 is better in 15 of the categories in Table 4-9, the TNAZ-based munition in one. For 19 of the categories there is no clear winner given the data available. By examining Tables 4-1 through 4-8 it can be seen that where the RDX-based munition is better it is generally much better, whereas the TNAZ-based GBU-24 is better by just more than the 15 percent differentiability margin.

Given the relative state of optimization for the systems, it is reasonable to expect the gap between the TNAZ-based and RDX-based systems to narrow for those comparators where the RDX-based system is better. The RDX-based system being a mature technology would not be expected to see significant changes in emissions or consumption. The same may not be said for the TNAZ-based system since much work on optimization of the synthesis reactions is occurring, which will be followed by further optimization achieved through large scale production. This action would be expected to tip the balance away from the RDX-based system being better in so many comparators.

Other unknowns include the true values for Transportation-, Waste Management-, and Off-site Electricity Production-related emissions for the TNAZ-based system. As was discussed above, no data were available on these activities from the LANL modeling efforts so a judgement was made to substitute the equivalent information from the RDX-based system.

These substitutions directly produce ties in 15 of the comparators. Some of these values are probably close to the true value, such as the Transportation-related emissions and consumption where the masses and distances traveled may not change much between the systems. Emissions from Waste Management may actually be lower than modeled for the TNAZ-based system since the TNAZ is recycled; however, Resource and Energy Consumption may increase since the TNAZ is melted out of the bomb casing. Off-site Electricity Production Emissions and Consumption are also expected to decrease since the amount of electricity used for the TNAZ-based system is approximately one-half that used for the RDX-based system. This would have the effect of changing seven of the comparators from a tie to being better under the TNAZ-based system (Total Non-Listed Emissions, Air Emissions, Listed Emissions - Off-site Electricity Production, Non-Listed Emissions - Off-site Electricity Production, Geologic and Biotic Resource Consumption - Off-site Electricity Production, Intermediate Materials Consumption - Off-site Electricity Production, and Energy Consumption - Off-site Electricity Production).

Based upon this qualitative analysis the true picture might look like Table 5-1. The RDX-based munition is better for 18 comparators, the TNAZ-based munition for 10, and which of the two systems is better cannot be determined for seven comparators.

Table 5-1. Life Cycle Inventory Summary Comparison (after Qualitative Adjustments for Data Quality)

Comparator	RDX-based GBU-24	TNAZ-based GBU-24
Total Emissions	•	
Listed Emissions	•	
Non-Listed Emissions		•
Air Emissions		•
Wastewater Emissions	•	
Solid Wastes	•	
Listed Emissions - Precursor Production	•	
Listed Emissions - Military Facilities	•	
Listed Emissions - Transportation		
Listed Emissions - Waste Management		•
Listed Emissions - Off-site Electricity Production		•
Non-Listed Emissions - Precursor Production		
Non-Listed Emissions - Military Facilities		•

Comparator	RDX-based GBU-24	TNAZ-based GBU-24
Non-Listed Emissions - Transportation		
Non-Listed Emissions - Waste Management		•
Non-Listed Emissions - Off-site Electricity Production		•
Total Resource Consumption	•	
Geologic and Biotic Resources	•	
Intermediate Materials	•	
Geologic and Biotic Resources - Precursor Production	•	
Geologic and Biotic Resources - Military Facilities		
Geologic and Biotic Resources - Transportation		
Geologic and Biotic Resources - Waste Management	•	
Geologic and Biotic Resources - Off-site Electricity Generation		•
Intermediate Materials - Precursor Production	•	
Intermediate Materials - Military Facilities	•	
Intermediate Materials - Transportation		
Intermediate Materials - Waste Management	•	
Intermediate Materials - Off-site Electricity Generation		•
Total Energy Consumption	•	
Energy Consumption - Precursor Production	•	
Energy Consumption - Military Facilities	•	
Energy Consumption - Transportation		
Energy Consumption - Waste Management	•	
Energy Consumption - Off-site Electricity Generation		•

Two points can be made. First, the RDX-based system appears to be the more environmentally beneficial at this time. Second, the TNAZ-based system does not appear to offer the potential to reduce the amount of Listed wastes emitted during GBU-24 production by the 50 percent goal. In fact, the TNAZ-based system will likely *increase* the amount of listed waste emitted. Currently the TNAZ-based system produces an estimated 18 pounds of Listed waste for every pound of Listed waste produced by the RDX-based system. To meet the goal, the TNAZ-based system would need to see a reduction in Listed wastes emitted of over 97 percent from current estimates.

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Appendix A

RDX-based GBU-24 LCI Inventory

GBU-24 Baseline Life Cycle Inventory

Item	Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise)									
	RMA & Offsite	HSAAP		MCAAP				Service/ Waste	Energy	
	Material Processing	Material Processing	Energy Production	Material Processing	Energy Production	NSWC-IH Demil.	Transport. (All)	Manage. Offsite	Production Offsite	Total
Listed Wastes										
Air Emissions										
Acetic acid	0	21								21
Acetone		4		0						4
Aluminum powder				0						0
Cyanox dust				0						0
Cyclohexanone		4								4
Hydrocarbons	236						1			237
Nitric acid		0								0
NOx	96	2	16		34	11	3		61	223
SOx	26		44		0				108	177
Stoddard solvent				3						3
Wastewater Emissions										
Acetic acid	0									0
Acetone				0						0
Ammonia	0									0
Hydroxide	0									0
Methanol										0
Phenol	0									0
Sulfuric acid	4									4
Trichloroethane				7		217				224
Solid Wastes										
Aluminum				0						0
Aluminum oxide	255									255
Pot Liner	3									3
RDX				0						0
Styrene resin				3						3
Non-Listed Wastes										
Air Emissions										
Asphaltic particulates				1						1
CO	32		6		5	1	1		7	52
CO2	2,490	0	6,041	0	1,407	209	188	773	15,020	26,128
n-Heptane				0						0
n-Propyl acetate		1								1
Total Particulates	13		1		0				62	75
Unspecified	1		0		16				0	18
Wastewater Emissions										
Iron	1									1
n-Heptane				0						0
Oil	0									0
Other Acid	0									0
Other Metals	0									0
Sulfide	0									0
Total Dissolved Solids	96					12				108
Total Suspended Solids	4					12				16
Solid Wastes										
Aluminum sludge		41								41
Ash	41									41
Binder				0						0
Biosolids		55								55
Bottom ash			148						108	256
Catalyst				0						0
CXM-7		2		0						2
FGD Solids									149	149
Fly ash			188						386	574
PBXN-109				0						0
Recycle			(213)						(166)	(379)
Red Mud	155									155
Slag									41	41
Thermosetting compound				2						2
Unspecified Solid Waste	3,499									3,499
Resource Consumption										
Geologic and Biotic Resources										
Bauxite	390									390
Coal	827		2,208						6,225	9,260
Iron ore	2,243									2,243
Lime	5									5
Natural gas	2,548				1,882			58		4,489
Nitrogen	32									32
Oxygen	114									114
Petroleum	3,454				88			42		3,584
Rock salt	16									16

Intermediate Materials										
Acetic acid	0	108								108
Acetone		4	0	0	0					4
Ammonia	253									253
Binders		48								48
Cyclohexanone		4								4
DOA	43									43
Formaldehyde		181								181
Hexamine		137								137
Propyl acetate		4								4
Trichloroethane				224						224
Triphenyl phosphate		3								3
Energy Consumption (in MBTU/GBU-24)										
Coal	12.1		25.9						73.0	111
Electricity			1.7		2.3	0.5		1.5		6
Natural Gas					28.9			0.9		30
Petroleum					1.9		1.2	0.9		4

Appendix B

TNAZ-Based GBU-24 LCI Life Cycle Inventory

Suggest eliminating rows not in system

GBU-24 Baseline Life Cycle Inventory	Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise)					(TNAZ & Solvent Recycle)				
	RMA & Offsite	HSAAP		MCAAP				Service/ Waste	Energy	
Item	Material Processing	Material Processing	Energy Production	Material Processing	Energy Production	NSWC-IH Demil.	Transport. (All)	Manage. Offsite	Production Offsite	Total
Listed Wastes										
Air Emissions										
Acetaldehyde	0									0
Acetic acid										0
Acetimide	0									0
Acetone				0						0
Acetonitrile	0									0
Acid	0									0
Acrolein	0									0
Acrylamide	0									0
Acrylic acid	0									0
Acrylonitrile	0									0
Alachlor/Metolachlor	0									0
Aldehydes	0									0
Aluminum powder				0						0
Ammonia	4									4
Atrazine	0									0
Benzene	0									0
Chlorine	5									5
Chlorobenzene	0									0
Chlorpyrifos	0									0
Cyanazine	0									0
Cyanox dust				0						0
Cyclohexanone										0
Dichlorobenzene	0									0
Fonofos	0									0
Hydrazine	0									0
Hydrocarbons	1,256									1256
Hydrogen chloride	9									9
Hydrogen cyanide	0									0
Hydrogen sulfide	0									0
Isopropanol	0									0
Metals	0									0
Methane	0									0
Nitric acid	0						1			1
NO	0					3				3
N2O	1									1
NOx	22				34		3		61	121
Organic acids	0									0
Phosgene	0									0
Producer gas	280									280
Propene	0									0
Propylene	0									0
Pyridine	0									0
SOx	94				0				108	202
Sulfuric acid	0									0
Stoddard solvent				3						3
Toluene		1,982								1982
Terbufos	0									0
Wastewater Emissions										
Acetic acid										0
Acetone				0						0
Alachlor/Metalachlor	0									0
Ammonia	0									0
Atrazine	0									0
Chlorine	240									240
Chlorpyrifos	0									0
Cyanazine	0									0
Fonofos	0									0
Hydrazine	2									2
Hydroxide										0
Methanol										0
Organics	0									0
Phenol	0									0
Phosgene	10									10
? Pyridine	2,297									2297
Pyridine hydrochloride	3,356									3356
Sulfuric acid										0
Terbufos	0									0
Trichloroethane				7						7
Solid Wastes										
Acetic acid		2,743								2743
Acetaldehyde	4									4
Acetamide	0									0
Acetonitrile	0	2,864								2864

Acrolein	1									1
Acrylamide	0									0
Acrylic acid	2									2
Acrylonitrile	56									56
Aluminum				0						0
Aluminum oxide										0
Ammonia	0									0
BDNA, polymeric		122								122
BHMNA.HCL		991								991
DIAD.H2		991								991
Hydrogen chloride	0									0
Miscellaneous		22								22
Organics		99								99
Polyamine		84								84
Pot Liner										0
Potassium ferricyanide		198								198
2-Propanol		353								353
Pyridine	0									0
RDX				0						0
Solvent		1,029								1029
Styrene resin				3						3
TNAZ		42								42
Triphenylphosphine		1,348								1348
Non-Listed Wastes										
Air Emissions										
Asphaltic particulates				1						1
CO	219				5	0	1		7	232
CO2	5,038			0	1,407	114	188	773	15,020	22,541
Fluoride	0									0
n-Heptane				0						0
Oxygen		44								44
PM10	15									15
n-Propyl acetate										0
Total Particulates	290				0				62	353
Unspecified					16				0	17
Wastewater Emissions										
Ammonium nitrate		63								63
BOD	1									1
COD	1									1
Iron										0
n-Heptane				0						0
Nitrates	6									6
Oil	0									0
Other Acid	2									2
Other Metals	2									2
Phosphorus	0									0
Potassium	1									1
Sodium	16									16
Sodium chloride		219								219
Sodium formate		252								252
Sodium hydroxide		0								0
Sodium nitrite		672								672
Sodium sulfate	11	2,003								2,014
Sulfide										0
Total Dissolved Solids	2									2
Total Suspended Solids	13									13
Water	11,631,971	21,321				1,534				
Solid Wastes										
Aluminum sludge						48				48
Ash	16					61				77
Binder				0						0
Biosolids										0
Bottom ash									108	108
Catalyst				0						0
CXM-7 TNAZ Expl. Material				0						0
Ethanol		1,260								1,260
FGD Solids									149	149
Formic acid		203								203
Fly ash									386	386
Molybdenum trioxide	0									0
Paraformaldehyde		96								96
PBXN~~-109~~				0		127				128
Propylene	0									0
Recycle									(166)	(166)
Red Mud										0
Salts		84								84
Slag									41	41
Thermosetting compound				2						2
Unspecified Solid Waste	656					5				661
Resource Consumption										

Geologic and Biotic Resources										
Bauxite	1									1
Clay	0									0
Coal	1,363,352								6,225	1,369,576
Iron ore	4									4
Lime	149									149
Natural gas	2,154,926				1,882			58		2,156,866
Nitrogen										0
Oxygen										0
Petroleum	342,162				88	6		42		342,298
Phosphate rock	49									49
Potassium chloride	14									14
Rock salt	6,335									6,335
Sand	0									0
Soil	3,769									3,769
Sulfur	19									19
Water	2,491,013	8				2,591				2,493,612
Intermediate Materials										
Acetic acid	3,164									3,164
Acetone				4	0					4
Activated carbon	1					5				5
Ammonia	1									1
Antifoam Agent		0								0
Benzene	1,399									1,399
Binders										0
Chlorine	2,464									2,464
CO	272									272
Cyclohexanone										0
DOA										0
Eth3PO4	9									9
Ethylene glycol	0									0
Formaldehyde										0
Free Base		643								643
Freon	0									0
Hexamine										0
Hydrazine	155									155
Hydrochloric acid		160								160
Hydrogen peroxide		165								165
Isopropanol	582									582
Nitromethane		282								282
Paraformaldehyde		630								630
Phosgene	957									957
Potassium ferricyanide		198								198
2-Propanol		353								353
Propoene	639									639
Propyl acetate										0
Pyridine	4,594									4,594
Sodium hydroxide	24									24
Sodium nitrite		928								928
Sodium persulfate		2,003								2,003
Sulfuric acid	8									8
Toluene		1,982								1,982
Trichloroethane				224						224
Triphenyl phosphate										0
Energy Consumption (in MBTU/GBU-24)										
Steam	33					1,695				1,728
Coal					2.3				73.0	75
Electricity	1.2							1.5		3
Hydropotential	12.5									12
Natural Gas					28.9			0.9		30
Nuclear Energy	102.1									102
Petroleum					1.9		1.2	0.9		4

Appendix C

TNAZ-Based GBU-24 Life Cycle Inventory Model

lb/lb TNAZ	Precursor materials and inputs for TNAZ (Oct 95)	Factored Use lb/lb precursor	Module in LCI
1.33	Formaldehyde (37%)	1	
1	Methanol	1	
1	Synthesis gas	1	
1.04631263	Coal	1.04631263	
0.596333404	Oxygen	0.596333404	
1.397873673	water	1.397873673	
0.5	Air (Oxygen)	0.5	
3.29	NIB-Glycerol (50%)	1	
0.331156299	Nitromethane	0.331156299	
1	Petroleum gas	0.331156299	
1	Nitric acid	0.331156299	
0.3	Paraformaldehyde	0.3	
0.662171432	Formaldehyde (37%)	0.19865143	
2.33	di isopropylazodicarboxylate	1	
0.667651524	Azodicarboxyl Chloride	0.667651524	
1.80902464	Phosgene	1.207798059	
0.724068226	Chlorine	0.874528197	
0.286032785	Carbon monoxide	0.345469842	
0.0005	Activated Carbon	0.000603899	
0.293090214	Hydrazine	0.353993792	
1.37755102	Ammonia	0.487644509	
3.403061224	Sodium Hypochlorite	1.204662547	
0.238803573	NaOH	0.287677721	
1.058327572	Chlorine	1.274927588	
0.648379344	Chlorine	0.432891458	
0.660415095	isopropanol	0.660415095	
0.725707656	Propylene	0.479268291	
0.008567382	Sulfuric acid	0.005658028	
3.02	Triphenyl phosphine	1	
1.739385713	Gringard reagent of benzene	1.739385713	
0.913761009	Chlorobenzene	1.589382845	
0.685027408	Benzene	1.08877081	
0.629945184	Chlorine	1.001224069	
0.197350102	Magnesium	0.343267948	
0.581718484	trichlorophosphine	0.581718484	
0.237401689	Phosphorous	0.138100951	
0.815298879	Chlorine	0.474274428	
5.57	Acetic anhydride	1	
1.457117595	Acetic acid	1.457117595	
0.485686352	Methanol	0.707702129	
1.04631263	Coal	0.740477675	
	Carbon monoxide	0	
0.428266893	Coal	0	
0.81	tert-butylamine	1	
1.332284697	tert-butylchloride	1.332284697	
0.673474147	2 methyl propylene	0.8972593	
0.815171249	Chlorine	1.086040181	
0.245109723	Ammonia	0.245109723	
0.664519692	Sodium hydroxide	0.664519692	
8.8	Sodium hydroxide (50%)	1	
0.59	rock salt	0.59	
1.11	Hydrochloric acid (37%)	1	
1.6	Hydrogen peroxide (50%)	1	
0.056165471	Hydrogen	0.056165471	
0.891481976	Oxygen	0.891481976	
3	water	3	
0.001	Ethyl anthroquinone Catalyst	0.001	
3.6	Iso propanol	1	
0.9	Propylene	0.9	
	Crude oil	0	
0.0125	Sulfuric acid	0.0125	
2.62	2 butanone (MEK)	1	
1	2 butanol	1	
1	n butene (mix)	1	
1.879988255	Naphtha	1.879988255	
1.73292E-05	ammonia	1.73292E-05	
2.27	Sodium nitrite (s)	1	

0.47	Potassium ferrocyanide	1
0.474903847	KCN	0.474903847
0.379525372	HCN	0.180238059
1.046829519	KCl (or KBr)	0.497143365
0.196704311	FeCN2	0.196704311
0.278354486	HCN	0.132191616
0.575163641	Fe (powder)	0.273147426
	Iron ore	0
4.76	Sodium persulfate	1
1.213756073	Na2SO4	1.213756073
5	Methyl t-butyl ether (MTBE)	1
0.454373948	Methanol	0.454373948
0.8	methane	0.363499158
0.795628321	Isobutene	0.795628321
0.01	Iron chloride 42o Be	1
	Iron metallic	0
	Hydrochloric acid	0
0.92	Nitric acid (70%)	1
0.549672131	Ammonia	0.549672131
10.70491803	Air	10.70491803
0.56	ammonium nitrate (s)	1
0.21243083	Ammonia	0.21243083
0.909292035	Nitric acid	0.909292035
2.24	Ethanol SDA3A	1
	Corn, sorghum	0
6.8	Acetonitrile	1
0.386722942	Ammonia	0.386722942
0.956630435	Propylene	0.956630435
10	Nitrogen gas	1
	Air	0
100	Deionized water	1
	Sulfuric acid	0
	Sodium Hydroxide	0
	Water (natural sweet)	0
0.01	Antifoam, DOW 2210	1

Formaldehyde Production Life Cycle Invnetory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
NOx	0.000025	
CO	0.041807	
SOx	0.016888	
Formaldehyde	0.000005	
Methanol	1.21E-05	
Ammonia	1.46E-07	
Sulfuric acid	2.22E-09	
TSP	0.007691	
CO2	0.102758	
Hydrocarbons	0.031006	
Water		
Solid Wastes		
Production waste (not innert)	0.032566	
Resource Consumption		
Energy	2.812753	kWh/lb
Oxygen (from air)	0.53	
Natural Gas	0.202	
CO2	0.183	
Water	0.127	
Methanol	0.47	
Air	5.76	
Coal	0.428267	

NIB-Glycerol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air Emissions	
1,2-butylene oxide	1.9869E-07
2-nitropropane	0.00017369
acetaldehyde	2.0085E-05
acetone	1.3478E-05
acetonitrile	6.9212E-06
ammonia	0.00025343
BrClF2C	6.292E-07
BrF3C	2.3678E-06
Chlorine	1.2915E-06
Cl2F2C	0.0003146
Formaldehyde	0.00010352
Hydrogen cyanide	1.8396E-05
methanol	7.8202E-06
naphthalene	0.00018358
nitric acid	1.573E-06
NOx	8.3961E-06
CO	0.00830507
SOx	0.00335492
Sulfuric acid	4.4145E-10
TSP	0.00152788
CO2	0.02041303
Hydrocarbons	0.00615947
Wastewater Emissions	
ammonia	4.9673E-07
Hydrogen cyanide	3.3116E-08
2-nitropropane	
acetaldehyde	0.00297512
acetone	0.00159669
acetonitrile	0.00130257
ammonia	4.0683E-05
Formaldehyde	2.2717E-05
Hydrogen cyanide	1.8876E-06
methanol	0.00262238
naphthalene	1.8876E-06
nitric acid	0.00018373
Wastewater	23.0110595
Solid Wastes	
Production waste (not innert)	0.00646925

Resource Consumption

Steam	0.00976429	
River Water	23.0012953	
Electricity	0.01192499	kWh
Energy	0.55875742	kWh
Oxygen (from air)	0.10528526	
Natural Gas	0.04012759	
CO2	0.03635321	
Water	0.02522873	
Air	1.14423223	
Coal	0.08507583	

Diisopropylazodicarboxylate Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Phosgene	5.78E-05
Hydrazine	3.56E-07
Isopropanol	6.2E-07
Pyridine	5.59E-06
HCl	1.59E-05
Cl2	1.71E-05
CO	0.004051
TSP (PM-10)	0.000383
SOx	0.002005
NOx	0.002876
CO2	0.849661
Ammonia	0.001024
Methane	3.64E-10
Hydrocarbons	0.006136
Isopropanol	0.000431
Propene	1.69E-05
H2S	4.79E-06
Heavy metals	4.79E-07
H2SO4	3.62E-07
Wastewater	
Phosgene	0.009784
Hydrazine	0.001585
Pyridine	2.34707
Pyridine HCl	3.428944
Na2SO4	0.011167
COD	0.000113
BOD	2.3E-05
Acid as H+	0.000995
Metal ions	0.000354
Cl2	0.120565
Dissolved Organics	9.59E-06
Total Suspended Solids	0.005836
Crude oil	4.79E-05
Total Dissolved Solids	0.000335
Phenol	3.35E-05
Sodium	0.008036
Solid Wastes	
Production waste (not innert)	0.288446

Resource Consumption

Phosgene	0.978355	
Hydrazine	0.158474	
Isopropanol	0.594389	
Cl2	1.220271	
Pyridine	4.694139	
CO	0.277794	
Activated Carbon	0.000604	
Natural Gas	1.03912	
Electric Power	0.067589	kWh
Steam	0.185305	
Heat Energy (fossil fuel)	0.433116	kWh
Propene	0.653158	
Sulfuric acid	0.007711	
NaOH	0.006289	
Coal	0.698641	
Hydropower	2.128203	
Fission	17.67491	
Iron ore	0.001774	
Limestone	0.0511	
Bauxite	0.000144	
Rock salt	3.297246	
Clay	9.59E-06	
Water	4.615634	
Crude Oil	0.242245	
Sand	5.74E-05	

Triphenyl phosphine Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
Cl2	0.003882	
Benzene	4.92E-06	
HCl	0.006726	
dichlorobenzenes	3.98E-06	
chlorobenzene	6.48E-05	
Water		
COD	0.000233	
BOD	2.62E-05	
Acid as H+	0.000545	
Metal ions	0.000525	
Cl2	0.062069	
Total Suspended Solids	0.003082	
Crude oil	0.000109	
Total Dissolved Solids	0.000662	
Hydrocarbons	0.000103	
Phenol	1.09E-06	
Sodium	0.004131	
Solid Wastes		
Production waste (not innert)	0.156592	
Resource Consumption		
Heat Energy (fossil fuel)	0.880406	kWh
Electric Power	4.73E-06	kWh
Benzene	1.102986	
Chlorine	1.00113	
Sodium hydroxide (dry bassis)	0.013772	
Natural Gas	1.159743	
Crude Oil	0.83093	
Coal	0.383234	
Hydropower	1.138573	
Fission	9.277315	
Iron ore	0.001122	
Limestone	0.027564	
Bauxite	0.00024	
Rock salt	1.791668	
Clay	2.18E-05	
Water	3.733043	
Sand	2.95E-05	

Acetic anhydride Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Producer gas	0.129049
Cinder	0.110446
Flue gas	0.494985
TSP	0.01665
SOx	0.03655
CO	0.090473
CO2	0.222453
Hydrocarbons	0.067123
Wastewater	
Water	5347.48
Solid Waste	
Production waste (not innert)	0.023047
Resource Consumption	
AcOH	1.457118
NH3	0.000284
Eth3PO4	0.004325
Air	0.251604
Natural Gas	0.015179
EthGlycol	2.68E-05
Freon	2.72E-06
Filtered Water	6.638878
Steam	7.593786
River Water	803.3346
Coal	0.927121

tert-Butylamine Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
TSP (PM-10)	1.45E-10	
SOx	7.06E-06	
NOx	1.5E-09	
CO	0.001936	
CO2	0.299867	
Ammonia	0.000515	
Methane	1.83E-10	
Hydrocarbons	0.001157	
Water		
COD	1.75E-05	
BOD	5.25E-06	
Acid as H+	0.000595	
Metal ions	0.000158	
Cl2	0.073524	
Total Suspended Solids	0.003501	
Total Dissolved Solids	8.75E-05	
Sodium	0.004902	
Solid Wastes		
Production waste (not innert)	0.173305	
Resource Consumption		
Natural Gas	0.471558	
Crude Oil	0.172421	
Coal	0.407813	
Hydropower	0.160052	kWh
Fission	1.337611	kWh
Iron ore	0.001012	
Limestone	0.027178	
Rock salt	1.706175	
Water	4.499391	
Sand	3.5E-05	
Electric Power	0.033972	kWh
Steam	0.011736	kWh

Sodium hydroxide Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
Water		
COD	0.00001	
BOD	0.000003	
Acid as H+	0.00034	
Metal ions	0.00009	
Cl2	0.042	
Total Suspended Solids	0.002	
Total Dissolved solids	0.00005	
Sodium	0.0028	
Solid Wastes		
Production waste (not innert)	0.099	
Resource Consumption		
Natural Gas	0.176505	
Crude Oil	0.129783	
Coal	0.217294	
Hydropower	0.09259	kWh
Fission	0.748543	kWh
Iron ore	0.00046	
Limestone	0.0105	
Rock salt	0.59	
Water	5.3	
Sand	0.00002	

Isopropanol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
Isopropanol	0.000652	
Propene	2.56E-05	
TSP	0.00072	
SOx	0.003763	
NOx	0.0054	
CO	0.00036	
CO2	0.475251	
H2S	0.000009	
HCl	0.000009	
Hydrocarbons	0.007201	
Heavy metals	9E-07	
H2SO4	8E-07	
Water		
Na2SO4	0.01691	
COD	0.00018	
BOD	0.000027	
Acid as H+	0.000036	
Metal ions	0.00018	
Cl2	0.000045	
Dissolved Organics	0.000018	
Total Suspended Solids	0.00018	
Crude oil	0.00009	
Total Dissolved Solids	0.00036	
Phenol	0.000063	
Solid Wastes		
Production waste (not innert)	0.0081	
Resource Consumption		
Heat Energy (fossil fuel)	0.655825	
Electric Power	4.68E-06	
Propene	0.989011	
Natural Gas	0.462717	kWh
Coal	0.018379	kWh
Hydropower	0.013608	
Fission	0.026082	
Iron ore	0.00018	
Limestone	0.00009	kWh
Bauxite	0.00027	kWh

Rock salt	0.0054
Clay	0.000018
Water	1.44

MEK Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
Cl2	4.18E-06	
Zinc oxides/Phosphates	1.136721	
TSP	0.0008	
SOx	0.004	
NOx	0.006	
CO	0.0004	
CO2	0.500021	
H2S	0.000001	
HCl	0.00001	
Hydrocarbons	0.007001	
Heavy metals	0.000001	
Ammonia	3.64E-08	
Methane	1.29E-14	
Water		
Dissolved Organics	3.73E-05	
COD	0.0002	
BOD	0.00004	
Acid as H+	0.00004	
Metal ions	0.0003	
Cl2	0.00005	
Total Suspended Solids	0.0002	
Crude oil	0.0001	
Total dissolved Solids	0.0004	
Hydrocarbons	0.00009	
Phenol	0.000001	
Solid Wastes		
P4 production waste (not innert)	5.85E-07	
Zinc Compounds	3.8E-05	
Production waste (not innert)	0.0083	
Resource Consumption		
Chlorine	1.73E-05	
Natural Gas	0.67741	
Crude Oil	0.825106	
Coal	0.017555	
Hydropower	0.00756	kWh
Fission	0.02772	kWh
Iron ore	0.0002	

Limestone	0.0001	
Bauxite	0.0003	
Rock salt	0.006	
Clay	0.00002	
Water	1.6	
Electric Power	2.4E-06	kWh
Steam	8.3E-07	kWh

MTBE Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
MTBE	7.32E-06	
Methanol	2.14E-05	
Ammonia	4.09E-09	
TSP	0.004131	
SOx	0.010854	
CO	0.019308	
CO2	0.444505	
Hydrocarbons	0.019659	
NOx	0.004774	
H2S	7.96E-07	
HCl	7.96E-06	
Heavy metals	7.96E-07	
Water		
MTBE	3.26E-08	
Methanol	5.43E-06	
Ammonia	1.66E-07	
COD	0.000159	
BOD	3.18E-05	
Acid as H+	3.18E-05	
Metal ions	0.000239	
Cl2	3.98E-05	
Dissolved Organics	1.59E-05	
Total Suspended Solids	0.000159	
Crude oil	7.96E-05	
Total Dissolved Solids	0.000318	
Hydrocarbosn	7.16E-05	
Phenol	7.96E-07	
Solid Wastes		
Production waste (not innert)	0.021401	
Resource Consumption		
Electric Power	1.25E-08	kWh
Isobutylene	0.844446	
Methanol	0.273011	
Coal	0.208561	
Natural Gas	0.538952	
Crude Oil	0.656478	
Hydropower	0.006015	kWh

Fission	0.022054	kWh
Iron ore	0.000159	
Limestone	7.96E-05	
Bauxite	0.000239	
Rock salt	0.004774	
Clay	1.59E-05	
Water	1.273005	

Nitric acid Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
NOx	1.04E-05
TSP (PM-10)	3.25E-10
SOx	1.58E-05
CO	0.004342
CO2	0.672469
Ammonia	0.001154
Methane	4.11E-10
other organic	0.002594
Wastewater	
Water	69.48701
Solid Waste	
Resource Consumption	
Steam	0.029485
River Water	69.45752
Electricity	0.112193 kWh
Natural Gas	0.580032
Steam	0.026318 kWh

Ammonium nitrate Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity	
Air		
NOx	1.37E-05	
Wastewater		
Water	91.78143	
Solid Waste		
Resource Consumption		
Steam	0.038946	kWh
River Water	91.74249	
Electricity	0.047564	kWh

Ethanol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
NOx	0.002435
SOx	0.001701
PM-10	0.011892
Total Particulate	0.009237
CO	0.00573
CO2	0.547669
Non-Methane Org. Comp.	0.000729
Methane	3.09E-06
N2O	0.000272
HCL	7.26E-06
Ammonia	0.000443
Chlorine	7.95E-07
Sulfuric Acid	4.9E-07
Hydrocarbons	0.000343
Aldehydes	1.67E-05
Organic Acids	1.32E-06
Fertilizer N20	0.000411
Fertilizer NO	0.000252
Particulate	0.000139
Nitric Acid	6.13E-06
Fluoride	5.58E-07
Acid Mist	3.14E-05
Herbicides	0.000157
Alachlor	3.13E-05
Atrazine	5.78E-05
Metalachlor	3.83E-05
Cyanazine	2.99E-05
Insecticides	2.49E-05
Fonofos	4.64E-06
Turbufos	1.23E-05
Chlorpyrifos	7.98E-06
Water	
Total Water Emission	0.610304
Ammonia	5.7E-06
Chlorine	3.26E-08
BOD5	0.000407
TSS	0.000509
Herbicides	6.11E-06
Alachlor	2.74E-07

Atrazine	2.97E-06
Metalachlor	1.2E-06
Cyanazine	1.67E-06
Insecticides	5.2E-07
Fonofos	8E-08
Turbufos	2.12E-07
Chlorpyrifos	2.28E-07
Nitrates (as nitrogen)	0.004885
Phosphorous	0.000122
Potassium	0.000504

Solid Wastes

HCL	1.12E-07
Ammonia	1.83E-07
Coal Ash	0.012993

Resource Consumption

Natural gas	1705.936	
Coal	1079.272	
Electricity	0.084213	kWh
Water	276.1801	
Sulfur	0.001175	
Diesel	444.8868	Btu
LPG	99.77364	
Oil	58.12006	
Gasoline	112.5477	
Limestone	0.039864	
Sulfur	0.013546	
Water	275.4681	
Phosphate Rock	0.038957	
Potassium Chloride	0.011404	
Soil	2.991136	

Acetonitrile Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

Item	Quantity
Air	
Cl2	1.33E-06
Acetonitrile	6.25E-06
Acrolein	1.22E-07
Acrylic acid	4.16E-09
Acrylonitrile	4.5E-05
Ammonia	0.000824
Hydrogen Cyanide	6.69E-05
Propylene	2.3E-05
Acetamide	1.39E-08
Acetaldehyde	5.41E-08
Acrylamide	3.09E-07
Pyridine	2.11E-07
Hydrocarbons	0.009633
TSP (PM-10)	0.000765
SOx	0.003838
NOx	0.00574
CO	0.003438
CO2	0.978218
Methane	2.89E-10
H2S	9.57E-06
HCl	9.57E-06
Heavy metals	9.57E-07
Water	
Ammonia	4.02E-07
COD	0.000191
BOD	2.87E-05
Acid as H+	3.83E-05
Metal ions	0.000191
Cl2	4.78E-05
Dissolved Organics	1.91E-05
Total Suspended Solids	0.000191
Crude oil	9.57E-05
Total Dissolved Solids	0.000383
Phenol	6.7E-05
Solid Wastes	
Acetonitrile	6.8E-08
Acrylonitrile	6.94E-09
Acetonitrile	4.72E-07

Acrolein	0.000222	
Acrylic acid	0.000861	
Acrylonitrile	0.019429	
Ammonia	2.91E-05	
Molybdenum Trioxide	2.64E-05	
Acetamide	8.32E-06	
Acetaldehyde	0.001291	
Acrylamide	0.000112	
Pyridine	1.53E-08	
LCI component	0.005274	
Propylene	7.63E-05	
Molybdenum Trioxide	0.000124	
Production waste (not innert)	0.00861	
Resource Consumption		
Heat Energy (fossil fuel)	0.112889	kWh
Electric Power	0.053599	kWh
Natural Gas	0.899915	
Steam	0.018516	kWh
Coal	0.019536	
Hydropower	0.014464	kWh
Fission	0.027723	kWh
Iron ore	0.000191	
Limestone	9.57E-05	
Bauxite	0.000287	
Rock salt	0.00574	
Clay	1.91E-05	
Water	1.530609	

Mass Balance on Unit Processes
Brown, Hamel and Hedman

Process No. (- = inflow, + = outflow)

Material	1	2	3	4	5	6	Total
Methanol	-0.54				0.07		-0.47
Air	-1.55		-0.81			-3.4	-5.76
Steam	-0.05	-0.5				0.55	0
Mixture	2.14	0	0	-1.07	-1.07		0
Loss							0
Condensate		0.5				-0.5	0
Fuel							0
Stack gas			0.81			3.4	4.21
Cooling water				0			0
Off gas				1.07			1.07
Formaldehyde					1		1
Makeup						-0.05	-0.05
Total	4.44089E-16	0	0	0	0	2.64E-16	7.08E-16

Notes: Inputs and outputs are lb. per lb. of formaldehyde produced.

Energy Balance on Unit Processes
Brown, Hamel and Hedman

Process No. (- = inflow, + = outflow)

Material	1	2	3	4	5	6	Total
Methanol	-4				4		0
Air							0
Steam	-60	-620				680	0
Mixture	58	342	500	-840	-60		0

Loss	6	226.5	120	90	4	30.7	477.2
Condensate		51.5				-51.5	0
Fuel			-800			-967	-1767
Stack gas			180			307.8	487.8
Cooling water				690			690
Off gas				60			60
Formaldehyde					52		52
Makeup							0
Total	0	0	0	0	0	5.68E-14	5.68E-14

Notes: Inputs and outputs are in BTU per lb. of formaldehyde produced.

Sheet Title: Methanol (for Acetic acid production by Eastman/Malinkrodt at Kingston)

Sheet Description: Engineering calculation (rough)
This page calculates the vendor emissions from a plant producing Acetic acid.
Not included are raw material production or extraction or water and energy use.
(Energy balance is assumed to be close to 0 due to exothermic producer gas synthesis process)

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed, 1991-4
Wiley Interscience,

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
Acetic acid	1.00E+00	kg
Coal Tar	1.05E-01	Kg
Total	1.10515212	Kg

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
TSP	Kg/Kg Acetic a	0.0085		Kg/Kg Acetic a	0.007691249		3
SOx	Kg/Kg Acetic a	0.018658783		Kg/Kg Acetic a	0.016883452		3
CO	Kg/Kg Acetic a	0.046186813		Kg/Kg Acetic a	0.041792268		3
CO2	Kg/Kg Acetic a	0.113563242		Kg/Kg Acetic a	0.102758018		3
total HC's	Kg/Kg Acetic a	0.034266829		Kg/Kg Acetic a	0.031006436		3
Water							
Solid Wastes							
Production waste	Kg/Kg Acetic a	0.035990206			0.032565839		
Resource Consumption							
Coal	Kg/Kg Acetic a	0.473300065		Kg/Kg Acetic a	0.428266893		
Methanol	Kg/Kg Acetic a	0.536757301		Kg/Kg Acetic a	0.485686352		

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Calculations

Acetic acid Production

Energy input
All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/kg ethylene	0		3	kg/kg ethylene	0	
Oil	MJ/kg ethylene	0	15	3	kg/kg ethylene	0	0.33622909
Natural Gas	MJ/kg ethylene	0		3	kg/kg ethylene	0	
Hydropower	MJ/kg ethylene	0		3			
Fission	MJ/kg ethylene	0		3			

Probably different mix in US

Material input
Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Methanol Carbonylation method

Stoichiometric ratios:

Methanol net	Kg/Kg Acetic a	0.533		
CO net	Kg/Kg Acetic a	0.467		
Methanol input	Kg/Kg Acetic a	0.536757301	0.993	0.993 conversion of methanol
CO input	Kg/Kg Acetic a	0.513186813	0.91	0.91 conversion of CO
Producer-Gas input	Kg/Kg Acetic a	1.694973756		from Faith Keyes and Clark's Industrial chemicals, 1975
Coal input	Kg/Kg Acetic a	0.473300065		

Emission calculation (Data from pg D and from AP42 Ed 4 Tbl 1.1-1)

Air				
CO released from process	Kg/Kg Acetic a	0.046186813	0.09	unconverted CO
Methane	Kg/Kg Acetic a	0.030509528		
CO2	Kg/Kg Acetic a	0.113563242		
Particulates	Kg/Kg Acetic a	0.0085	8.5	g/kg in Cyclone trap outlet (AP42 Ed 4 tbl 1.1-1)
Methanol	Kg/Kg Acetic a	0.003757301	0.007	unconverted assumed to escape in vent stream
SOx	Kg/Kg Acetic a	0.018658783	19.5*%S in Co	from AP 42 Ed 4 (1985) tbl 1.1-1
				Coal assumed to have 1% Sulfur and the coal tar product to have 0.4% sulfur
Land				
Ash	Kg/Kg Acetic a	0.035990206	0.094	Ash in coal (assumed recovered) but for air emission

CO production from Coal through synthesis gas (producer or manufactured)
Source: Page D calculations

Producer gas from Coal (Baddelsey)
25.30% mol CO 30.28% wt CO

Mw CO 28.016
Mw Produc 23.410686

Gas product yield from coal: 3.581182178 lb gas/lb coal

Co-Products:
source: calculated from data on this sheet and on sheet D
Coal tar heating value is median for data of Perry Ed 6 (1984) tbl. 9-12

Coal Tar	Kg/Kg Acetic a	0.10515212		
Energy equivalent	MJ/Kg Acetic a	4.153508743	39.5	MJ/Kg coal tar

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil					Kg/Kg Acetic acid		
Natural Gas					Kg/Kg Acetic acid		
Coal	Kg/Kg Acetic a	0.473300065		3	Kg/Kg Acetic acid	0.473300065	
Iron ore	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Methanol	Kg/Kg Acetic a	0.536757301		3	Kg/Kg Acetic acid	0.536757301	
Bauxite	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Rock salt	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Clay	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Output

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg Acetic a	0.0085			Kg/Kg Acetic acid	0.0085	
SOx	Kg/Kg Acetic a	0.018658783			Kg/Kg Acetic acid	0.018658783	
NOx	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
CO	Kg/Kg Acetic a	0.046186813			Kg/Kg Acetic acid	0.046186813	
CO2	Kg/Kg Acetic a	0.113563242			Kg/Kg Acetic acid	0.113563242	
H2S	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
HCl	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
total HC's	Kg/Kg Acetic a	0.034266829			Kg/Kg Acetic acid	0.034266829	
other organic	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Heavy metals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
BOD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Acid as H+	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Metal ions	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Cl2	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Dissolved Organics	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
suspended solids	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
crude oil	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
miscelanious dissolved mate	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Phenol	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert)	Kg/Kg Acetic a	0.035990206			Kg/Kg Acetic acid	0.00128	
Toxic chemicals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0.000001	

Sheet End

Coal type	Moisture	Sulfur		Heat value				
	%	%	%dry	Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11121.62			
HV bit A	2.9	0.6	0.62	14170	14593.2	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352.19			
Brown Coa German - R	55	0.3	0.67	4830	10733.33			
Sub bit A	13.9	0.6	0.70	10330	11997.68	SD=	1295.775	0.108169
Meta Anthracite	9	0.7	0.77	10080	11076.92	Avg=	11979.16	
LV bit	2.9	0.8	0.82	14400	14830.07	median		
Anthracite	4.3	0.8	0.84	12880	13458.73		27.86352	MJ/kg
Lignite	36.8	0.9	1.42	7000	11075.95		dry base	
MV bit	2.4	1.5	1.54	14490	14846.31			
Semi anthracite	2.1	1.7	1.74	13700	13993.87			
HV bit B	6.7	2.6	2.79	12390	13279.74			
HV bit C	15.4	2.9	3.43	10740	12695.04			

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

	Mwt	heat value	Rio Arriba,	Terrell, Tex	Stanton, Ka	San Juan, NM	Olds Field,	Cliffside, Texas	avg	SD (rel)
mol%		MJ/M^3								
Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8		
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8		
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7		
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8		
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5		
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22			
H2S	34.076	23.7		0.01			35.79			
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6	avg	SD (rel)
Mol wt:			16.62585	31.182	20.92126	21.28362	25.49289	20.44567	19.61024	10.79%
heating valu	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7	39.76667	12.81%
	MJ/KG		50.65847	12.42768	37.36678	49.25478	26.36029	33.63451	45.76001	13.03%
	0.0224M^3/mol			too high CO2 content for use			too high Sulfur content	too low heating value(?)		

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1984)
averaged from table 9-14

Btu/scf 1049.571

Synopsis of table 9-14

	Mwt	heat value	Baltimore	Columbus	Houston	Burmingham	Washington	Phoenix	avg	SD (rel)
mol%		MJ/M^3	Md	Ohio	Tx	Al	DC	Az		
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.37		
ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11		
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26		
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13		
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0		
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61		
H2S	34.076	23.7		0.01						
N2	28.013	0	0.5	0.21	21.14	2.14	0.42	1.37	avg	SD (rel)
Mol wt:			17.12629	16.93912	23.38022	17.32821	16.9628	18.17984	18.31941	15.84%

heating valu	MJ/M^3	39.2023	38.3444	38.4563	38.1952	38.8666	39.9483		38.83552	1.10%
	MJ/KG	51.27388	50.70597	36.84401	49.37455	51.32477	49.22167		48.12414	13.30%
	0.0224M^3/mol									

Manufactured gas

Data from KO 2 (1964) for "modern mechanical method"				Gas			gas heat value				Tar data	
	Moisture	Heating valueBtu/lb		Gas yield scf/ton		gas lb/lb co	Gross heat value Btu/s		Btu/ton coa	Btu/lb coal	Tar yield gal/ton	
		wet	dry	wet base	dry base		wet base	dry base	wet base	wet base	wet base	dry base
Anthracite	0.051	10800	11380.4	123900	130558.5		138	145.4162	17098200	8549.1	9.5	10.01054
Belgian Co	0.026	11980	12299.79	120900	124127.3		150	154.0041	18135000	9067.5	1	1.026694
Baddesley	0.05	12080	12715.79	116100	122210.5	3.581182	165.6	174.3158	19226160	9613.08	21	22.10526

On the basis of 10% tar production in the process the Baddesley type coal is used
This coal then provides 9613.08 gas heating value in Btu/lb coal

Baddesley coal ga							
compositionMWt		vol%	O2 per mol	mol O2 per mol gas			
CO2	44.01	6.7	0	0			
alkyls							
O2	31.9988	0	0	0			
CO	28.016	25.3	0.5	0.1265			
H2	2.0158	21	0.5	0.105			
CH4	16.043	1.8	2	0.036			
N2	28.013	45.2	0	0		0.578864	mol air producing mol gas
Gas Mwt	23.41069			0.2675	mol O2 per mol gas	1.277093	mol air to burn mol gas
				0.365631	kg O2 per Kg gas	1.855957	mol air used/mol gas
ideal gas density of producer gas				1.580041	kgair/kg gas	2.296221	kg air used / kg gas
0.9882	kg/m^3						
0.061691	lb/s cuf			d=Mw/0.0224			

physical data

Density of T	75	lb/cuf			Perry 6 (1984)
	1200	kg/m^3			
	10.01449	lb/gal			

Units

scf is volume in cubic feet at 60 Farenheit and 30" Hg — KO 2 (1964)

288.7056	42.2115	0.02369	

density	lb/cuf	lb/gal	kg/m^3		Perry 6 (1984)
	0.062428	0.008345	1		
	7.480519	1	119.8264		
	1	0.133681	16.01846		

mass	ton (short -	lb	kg		Perry 6 (1984)
	1	2000			
		2.204623	1		

Pressure	"Hg	N/m^2	atm	psia	Perry 6 (1984)
	1	3376.9	0.033327	0.489775	
	2.041754	6894.8	0.068046	1	
	30.00533	101325	1	14.69586	
		1			

Heat value	MJ/m^3	btu/scf	Perry 6 (1984)
	0.0373	1	

Energy	MJ	Btu	Perry 6 (1984) for steam table values
	0.001055	1	

molar				kg air per kg
dry air composition		Mwt	mass comp	component
N2	0.78084	28.0134	0.75521	1.324134
O2	0.20946	31.9988	0.231406	4.321406
CO2	0.00033	44.01	0.000501	1994.319
Ar	0.00934	39.948	0.012882	77.62792
total	0.99997	28.96409	1	

Sheet Title: Nitroethane/nitromethane

Sheet Description: Nitroethane/nitromethane

Nitroethane is produced as a co-product in the production of nitorethane, nitromethane, 1-nitropropane, and 2-nitropropane

References/Citations: TRI inventory for 1991 for W. R. Grace Deer Park, Tx Facility

Personal communication from the plant manager of the Deer Park Facility to John Becker, Sept 6, 1995, indicating plant capacity for nitroparaffins at 20,000,000 lb/yr while operating. Plant closed in 1992.

Kirk-Othmer Enclyclopedia of Chemical Technology. 3rd ed. 1978. v15. "Nitroparaffins

Summary Output:

Allocated LCI component		Units	Quantity	DQI
air emissions				
	1,2-butylene	lb/lb	0.0000006	2
	2-nitropropar	lb/lb	0.0005245	2
	acetaldehyde	lb/lb	6.065E-05	2
	acetone	lb/lb	0.0000407	2
	acetonitrile	lb/lb	0.0000209	2
	ammonia	lb/lb	0.0007652	2
	BrClF2C	lb/lb	0.0000019	2
	BrF3C	lb/lb	7.15E-06	2
	Chlorine	lb/lb	0.0000039	2
	Cl2F2C	lb/lb	0.00095	2
	Formaldehyd	lb/lb	0.0003096	2
	Hydrogen cy	lb/lb	5.555E-05	2
	methanol	lb/lb	1.635E-05	2
	naphthalene	lb/lb	0.0005544	2
	nitric acid	lb/lb	4.75E-06	2
water				
	ammonia	lb/lb	0.0000015	2
	Hydrogen cy	lb/lb	0.0000001	2
underground				
	2-nitropropar	lb/lb	0.0069671	2
	acetaldehyde	lb/lb	0.0089841	2
	acetone	lb/lb	0.0048216	2
	acetonitrile	lb/lb	0.0039334	2
	ammonia	lb/lb	0.0001229	2
	Formaldehyd	lb/lb	0.0000686	2
	Hydrogen cy	lb/lb	0.0000057	2
	methanol	lb/lb	0.0079189	2
	naphthalene	lb/lb	0.0000057	2
	nitric acid	lb/lb	0.0005548	2

Notes: The 4 co-products are produced as part of the same reaction.
Product percentage varies with operating conditions (Kirk-Othmer), but emissions must be considered on a lb/lb basis as 4 equal co-products.

Conversion Factors

Unit from	Unit to	Multiplier

Calculations

Table Title

Table Reference/Citation

LCI component		Raw/ Input Units	Raw/ Input Quan.	Raw/ put Std. Dev	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
air emissions								
	1,2-butylene	lb/yr	12		4	lb/lb	0.0000006	
	2-nitropropar	lb/yr	10490		4	lb/lb	0.0005245	
	acetaldehyde	lb/yr	1213		4	lb/lb	6.065E-05	
	acetone	lb/yr	814		4	lb/lb	0.0000407	
	acetonitrile	lb/yr	418		4	lb/lb	0.0000209	
	ammonia	lb/yr	15304		4	lb/lb	0.0007652	
	BrClF2C	lb/yr	38		4	lb/lb	0.0000019	
	BrF3C	lb/yr	143		4	lb/lb	7.15E-06	
	Chlorine	lb/yr	78		4	lb/lb	0.0000039	
	Cl2F2C	lb/yr	19000		4	lb/lb	0.00095	
	Formaldehyd	lb/yr	6192		4	lb/lb	0.0003096	
	Hydrogen cy	lb/yr	1111		4	lb/lb	5.555E-05	
	methanol	lb/yr	327		4	lb/lb	1.635E-05	
	naphthalene	lb/yr	11087		4	lb/lb	0.0005544	
	nitric acid	lb/yr	95		4	lb/lb	4.75E-06	
water								
	ammonia	lb/yr	30		4	lb/lb	0.0000015	
	Hydrogen cy	lb/yr	2		4	lb/lb	0.0000001	
underground								
	2-nitropropar	lb/yr	139342		4	lb/lb	0.0069671	
	acetaldehyde	lb/yr	179681		4	lb/lb	0.0089841	
	acetone	lb/yr	96431		4	lb/lb	0.0048216	
	acetonitrile	lb/yr	78668		4	lb/lb	0.0039334	
	ammonia	lb/yr	2457		4	lb/lb	0.0001229	
	Formaldehyd	lb/yr	1372		4	lb/lb	0.0000686	
	Hydrogen cy	lb/yr	114		4	lb/lb	0.0000057	
	methanol	lb/yr	158377		4	lb/lb	0.0079189	
	naphthalene	lb/yr	114		4	lb/lb	0.0000057	
	nitric acid	lb/yr	11096		4	lb/lb	0.0005548	

Notes: Based ont eh information supplied by the plant manager of a production capacity of 20,000,000 lb/yr.

Sheet End ========= ========= ========= ========= ========= ========= ========= ========= =========

Nitric Acid+ Ammonium Nitrate
Source: all data

Technical report HDC-125-95 Pg 14
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg solution	kg per kg HNO3	kg per kg NH4NO3
Product							
		Solution		1.356	1	1.7730496	2.3419204
		HNO3	0.564		0.564	1	1.3208431
		NH4NO3	0.427		0.427	0.7570922	1
		W	0.009		0.009	0.0159574	0.0210773
Inputs							
	Materials						
		HNO3	0.99	1.233	0.909292	1.6122199	2.1294895
		NH3		0.123	0.090708	0.1608297	0.2124308
		Steam		0.02255	0.0166298	0.0294854	0.0389457
		River Water		53.12	39.174041	69.45752	91.742485
	Energy						
		Electricity	kWhr	0.02754	0.0203097	0.0360102	0.0475638
Waste							
	Water return to river (Non-contact)			53.12	39.174041	69.45752	91.742485
	Steam Condensate to river (Non-contact)			0.02255	0.0166298	0.0294854	0.0389457
Air Emiossion							
		NOx (value is for NO2)		7.921E-06	5.841E-06	1.036E-05	1.368E-05

Nitric Acid concentration
Source: all data

Technical report HDC-125-95 Pg 12
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc. wt frac.	Raw data in lb	kg per kg solution	kg per kg HNO3
Product						
		Solution		1.233	1	1.2454545
		HNO3	0.99		0.99	1
		W	0.01		0.01	0.010101
Output						
	to IWTF	water		0.8595	0.6970803	0.8681818
		NaNO3/w	0.904	0.01295	0.0105028	0.0130808
		NaNO3	as pure	0.0117068	0.0094946	0.0118251
		water	as pure	0.8607432	0.6980886	0.8694376
		Mg(NO3)2/w	0.6	0.009053	0.0073423	0.0091444
Inputs						
	Materials					
		HNO3	0.61	2.031	1.6472019	2.0515152
		Na2CO3		0.007304	0.0059238	0.0073778
		City Water		0.08226	0.0667153	0.0830909
		MgO		0.001478	0.0011987	0.0014929
		Steam		2.9	2.351987	2.9292929
		River Water		28.81	23.365775	29.10101
	Energy					
		Electricity	kWhr	0.05507	0.0446634	0.0556263
Waste						
	Water return to river (Non-contact)			28.81	23.365775	29.10101
	Steam Condensate to river (Non-contact)			2.9	2.351987	2.9292929
Air Emiossion						
		NOx (value is for NO2)		0.003348	0.0027153	0.0033818

Nitric Acid production
Source: all data

Technical report HDC-125-95 Pg 10
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc. wt frac.	Raw data in lb	kg per kg solution	kg per kg HNO3			
Product									
	desired	Solution		2.031	1	3.3295082			
		HNO3	0.61		0.61	1			
		W	0.39		0.39	0.6393443			
Output							Oz troy	lb/Oz troy	(CRC '66)
	to Cat recovery	Plat Cat		2.715E-06			0.0000396	0.0685714	
		Pt	0.9		1.203E-06	4.006E-06			
		Pd	0.05		6.685E-08	2.226E-07			
		Rh	0.05		6.685E-08	2.226E-07			
	to IWTF	NH3		3.691E-05	1.817E-05	6.051E-05			
Inputs									
	Materials								
		NH3		0.3353	0.1650911	0.5496721			
		Air		6.53	3.2151649	10.704918			
		City Water		0.4369	0.2151157	0.7162295			
		Filtered Water		108.9	53.618907	178.52459	Oz troy	lb/Oz troy	
		Plat Cat		2.715E-06			0.0000396	0.0685714	
		Pt	0.9		1.203E-06	4.006E-06			
		Pd	0.05		6.685E-08	2.226E-07			
		Rh	0.05		6.685E-08	2.226E-07			
		Steam		0.2293	0.1129	0.3759016			
		River Water		54.42	26.794682	89.213115			
	Energy								
		Electricity	kWhr	0.1926	0.0948301	0.3157377			
Waste									
	Water return to river (Non-contact)			163.3	80.403742	267.70492			
	Steam Condensate to river (Non-contact)			0.2293	0.1129	0.3759016			
Air Emiossion									
		NOx (value is for NO2)		0.003348	0.0016484	0.0054885			

Nitric acid and Ammoniumnitrate synthesis
Area B Steam Plant
Source: for all data
Technical report HDC-125-95 Pg 26
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg Steam	kg per kg Steam		
Product								
		Steam		50.75	1	1		
						0.9230959	weighting	according to coal utilization
Output								
To Block Plant		Cinders		0.3436	0.0067704			
		Fly Ash		0.2655	0.0052315	0.0048292		
to IWTF		Boiler blowdown		1.269	0.0250049	0.0230819		
	with:	Phosphates						
		Sulfates						
		Sulfites						
		Cooling Water		11.45	0.2256158	0.208265		
	with:	fly ash						
		cinders						
Inputs								
	Materials							
		Coal		5.037	0.0992512	0.0916184		
		Air		70.52	1.3895567	1.282694		
		Filtered Water		63.43	1.2498522	1.1537334		
		Boiler Guard		0.0002684	5.289E-06	4.882E-06	Anionic polymer surfactant "BoilerGUARD APG", Calgon	
		Conquor3475		9.305E-05	1.833E-06	1.692E-06	Diethylhydroxylamine, hydroquinone, Calgon	
		C-1 Antifoam		8.459E-06	1.667E-07	1.539E-07	Akoxylated alcohol solution, Calgon	
		Rock Salt		0.01196	0.0002357	0.0002175		
		Sulfuric acid		0.01408	0.0002774	0.0002561		
	Energy							
		Electricity	kWhr	0.1756	0.0034601	0.003194		
Waste								
		Fly Ash to Landfill		0.3036	0.0059823	0.0055222		
Air Emiossion								
		VOCs		0.0001261	2.485E-06	2.294E-06		
		NOx		0.03451	0.00068	0.0006277		
		CO		0.01259	0.0002481	0.000229		
		SOx		0.09571	0.0018859	0.0017409		
		Particulates		0.001209	2.382E-05	2.199E-05		
		Flue gas		74.5	1.4679803	1.3550865		

Coal utilization breakdown for by product distribution

		lb/lb RDX
Coal	Coal	5.037
	Cinders	0.3436
	Ash	0.5691

Energy coal	4.1243	92.31%
Cinder Coal	0.3436	7.69%
Utilized coal	4.4679	100.00%

Nitric acid and Ammoniumnitrate synthesis
Area B Water filtration
Source: for all data
Technical report HDC-125-95 Pg 30
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg Filtered water
Product					
		Filtered water		560.2	1
Output					
to IWTF		Water		27.17	0.0485005
	with:	Alum		0.1154	0.000206
		Filter backwash		67.56	0.1205998
	with:				
Inputs					
	Materials				
		River water		655	1.1692253
		Hydrated lime		0.0008082	1.443E-06
		Al Sulfate		0.03795	6.774E-05
		Cl2		0.002547	4.547E-06
	Energy				
		Electricity	kWhr	0.7422	0.0013249
Waste					
Air Emiossion					

Industrial Wastewater Treatment Facility
Both areas
Source: for all data
Technical report HDC-125-95 Pg 32
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg wastewater	
Product						
Output						
Inputs						
	Materials					
IWTF streams		Wastewater		329.5	1	
		NaOH 20%		0.0314	9.53E-05	
		NaOH	0.2	0.00628	1.906E-05	
		water	0.8	0.02512	7.624E-05	
		Quicklime		0.002363	7.171E-06	
		FeCl2 25-35%		0.01109	3.366E-05	
		FeCl2	0.3	0.003327	1.01E-05	
		water	0.7	0.007763	2.356E-05	
		HCl 33%		0.0002453	7.445E-07	
		HCl	0.33	8.095E-05	2.457E-07	
		water	0.67	0.0001644	4.988E-07	
		Magnifloc 496		3.691E-05	1.12E-07	flocculant
		Filtered water		14.96	0.0454021	
	Energy					
		Electricity	kWhr	0.2042	0.0006197	
Waste						
		Treated Industrial waste water		344.3	1.0449165	
	landfill	Biological sludge		0.1533	0.0004653	
	landfill	Alum Sludge		0.1154	0.0003502	
Air Emiossion						

Sheet Title: Diisopropyldiazodicarboxilate (from dichlorodiazodialdehyde ClOCNNCOCl and isopropanol. It is a precursor in production of TNAZ)

Sheet Description: Emissions are from Engineering estimates, basic solvent is assumed to be pyridine at 2X excess and **NOT** recycled
Engineering calculation of the Energy requirements and precursor requirements .
Dichlorodiazodialdehyde manufacture from hydrazine and phosgene are included in the calculations
This page calculates the vendor emissions from a plant producing Diisopropyldiazodicarboxilate.
Not included are raw material production or extraction or water use.

References/Citations:

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output
Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	1993 Production			
202.2096	Diisopropyldiazodicarb	1.00E+00	kg	1.00E+00	kg	17,859.00	88.3192489	17859	1
						17,859.00			
dichlorodiazodialdehyde	Total	1.00	Kg	1.00E+00	Kg				
						As acetone cyanohydrin	60		

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
Phosgene	Kg/kg Diazo	5.71092E-05		Kg/kg Diazo	5.71092E-05		3
Hydrazine	Kg/kg Diazo	3.56014E-07		Kg/kg Diazo	3.56014E-07		3
Isopropanol	Kg/kg Diazo	6.19977E-07		Kg/kg Diazo	6.19977E-07		3
Pyridine	Kg/kg Diazo	5.58703E-06		Kg/kg Diazo	5.58703E-06		3
HCl	Kg/kg Diazo	1.0474E-05		Kg/kg Diazo	1.0474E-05		3
Wastewater							
Phosgene	Kg/Kg Diazo	0.009783551		Kg/kg Diazo	0.009783551		3
Hydrazine	Kg/Kg Diazo	0.001584742		Kg/kg Diazo	0.001584742		3
Pyridine	Kg/Kg Diazo	2.347069575		Kg/kg Diazo	2.347069575	**Without recycle**	3
Pyridine HCl	Kg/Kg Diazo	3.428944026		Kg/kg Diazo	3.428944026	**Without recycle**	3
Resource Consumption							
Phosgene	Kg/kg Diazo	0.978355132		Kg/kg Acetoni	0.978355132		3
Hydrazine	Kg/kg Diazo	0.158474177		Kg/kg Acetoni	0.158474177		3
Isopropanol	Kg/kg Diazo	0.594389188		Kg/kg Acetoni	0.594389188		3
Cl2	Kg/kg Diazo	0.350655953		Kg/kg Acetoni	0.350655953		3
Pyridine	Kg/kg Diazo	4.694139151		Kg/kg Acetoni	4.694139151		3

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Mw Benzen	78.1134	molar				kg air per kg
Mw Chlorin	70.9	dry air composition		Mwt	mass composition	component
Mw ClBz	112.56	N2	0.78084	28.0134	0.75521	1.324134
Mw Cl2Bz	147.01	O2	0.20946	31.9988	0.231406	4.321406
Mw HCl	36.4609	CO2	0.00033	44.01	0.000501	1994.319
Mw NaOH	39.9971	Ar	0.00934	39.948	0.012882	77.62792
		total	0.99997	28.96409	1	

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter — 42.29634021 mol/m^3 — 1.225075 kg/m^3

Calculations

Process description

HCl molecules produced	
2	Hydrazine and phosgene are mixed in 1:2 stoichiometric relationship in a cooled reactor containing a large excess of pyridine as a basic solvent.
2	Once conversion is complete Cl2 is bubbled through to react with the hydrogen bonds on the NN single bond.
2	Isopropanol is added in 2:1 stoichiometric ratio to the original hydrazine and reaction proceeds to final stage.
	Product solution is washed with water to remove pyridine and hydrochloric acid.

99% Conversion is assumed due to strong driving force provided by HCl production during reaction.
1% unreacted

Co-Products: Given above.

Resources:

Energy Input LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg Diazo	0			MJ/Kg Diazo	0	

Coal	MJ/kg Diazo	0		Kg/kg Diazo	0
Oil	MJ/kg Diazo	0	15	Kg/kg Diazo	0
Natural Gas	MJ/kg Diazo	0		Kg/kg Diazo	0
Hydropower	MJ/kg Diazo	0			0
Fission	MJ/kg Diazo	0			0
Electricity (generic)	MJ/kg Diazo	7.060834755		MJ/Kg Diazo	7.060834755

Energy requirement

Cal/mol MJ/kg Diazo

Reaction temperature is assumed to be kept constant by removal of all heat formed during the reaction

Electric Demand

Electricity refrigeration of reaction tank MJ/Kg 4.942584328 **7.060834755** heat energy to disperse is calculated from HCl formation only.
efficiency of refrigeration electricity 0.7

7.8726E-08 MJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

These are guesses

Coolers **#REF!**
Total #REF! MJ/Kg Diazo

source: Stoichiometric calculations

Material Input

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Oil	Kg/kg Diazo	0		4	Kg/kg Diazo	0	
	Natural Gas	Kg/kg Diazo	0		4	Kg/kg Diazo	0	
	Coal	Kg/kg Diazo	0		4	Kg/kg Diazo	0	
98.9164	Phosgene	Kg/kg Diazo	0.978355132		4	Kg/kg Diazo	0.978355132	
32.045	Hydrazine	Kg/kg Diazo	0.158474177		4	Kg/kg Diazo	0.158474177	
60.0956	Isopropanol	Kg/kg Diazo	0.594389188		4	Kg/kg Diazo	0.594389188	
70.906	Cl2	Kg/kg Diazo	0.350655953		4	Kg/kg Diazo	0.350655953	
79.1	Pyridine	2 Kg/kg Diazo	4.694139151		5	Kg/kg Diazo	4.694139151	
	Water	Kg/kg Diazo	0		4	Kg/kg Diazo	0	

Air

Vapor P mmHg @ 25 C	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.	Partial P mmHg @ 25 C
	TSP	Kg/Kg Diazo	0		3	Kg/kg Diazo	0		
	SOx	Kg/Kg Diazo	0		3	Kg/kg Diazo	0		
	NOx	Kg/Kg Diazo	0		3	Kg/kg Diazo	0		
1428	Phosgene	Kg/Kg Diazo	5.71092E-05		3	Kg/kg Diazo	5.71092E-05		2.1743
169.6428571	Hydrazine	Kg/Kg Diazo	3.56014E-07		3	Kg/kg Diazo	3.56014E-07		0.0418
42	Isopropanol	Kg/Kg Diazo	6.19977E-07		3	Kg/kg Diazo	6.19977E-07		0.0389
gas	Cl2	Kg/Kg Diazo	0		3	Kg/kg Diazo	0		
24.27419355	Pyridine	Kg/Kg Diazo	5.58703E-06		3	Kg/kg Diazo	5.58703E-06		0.2660
36480	HCl	Kg/Kg Diazo	1.0474E-05		3	Kg/kg Diazo	1.0474E-05		1.0819
	HC total	Kg/Kg Diazo	0		3	Kg/kg Diazo	0		
	Heavy meta(Cd+Ni+Cr)	Kg/Kg Diazo	0		3	Kg/kg Diazo	0		Total volatiles
									6.4254

d Pyridine 981.9 kg/m^3 assumed volume in condenser is pyridine
0.004781 m^3 0.201801 mol gas

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
BOD	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Acid, H+ (Phosphoric)	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Metal ions	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Cl2	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	

Phosgene	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Hydrazine	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Isopropanol	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Cl2	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Pyridine	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	
Pyridine HCl	Kg/Kg Diazo	0		3	Kg/kg Diazo	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert)	Kg/Kg Diazo	0		5	Kg/kg Diazo	0	
Diazo	Kg/Kg Diazo	0		5	Kg/kg Diazo	0	
Pyridine	Kg/Kg Diazo	0			Kg/kg Diazo	0	
Heavy metals (Cadmium, Nickel, C	Kg/Kg Diazo	0		5	Kg/kg Diazo	0	

Deep well injection

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ nput Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Diazo	Kg/Kg Diazo	0			Kg/kg Diazo	0	
Phosgene	Kg/Kg Diazo	0.009783551			Kg/kg Diazo	0.009783551	
Hydrazine	Kg/Kg Diazo	0.001584742			Kg/kg Diazo	0.001584742	
Pyridine	Kg/Kg Diazo	2.347069575			Kg/kg Diazo	2.347069575	**Without recycle**
Pyridine HCl	Kg/Kg Diazo	3.428944026			Kg/kg Diazo	3.428944026	**Without recycle**

Sheet End ======== ================ ============= =========== ========== ========== ============= ============ ========== ================== ======= =======

Sheet Title: Phosgene (from chlorine and carbon monoxide. Phosgene is used in production of TNAZ precursor diisopropyldiazodicarboxylate)

Sheet Description:
Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing Phosgene.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th edSource for physical data and unit conversions
McGraw Hill, 1984

CRC Handbook of Chemistry and Physics, 66thSource for physical data and unit conversions

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

Summary Output
Co-product Allocation Calculations

Source:
US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	BP deg C	Sp G	Vapor density relative to air
98.92	Phosgene	1.00E+00	kg	1.00E+00	kg	8.2	1.392	3.4
	Total	1.00E+00	Kg	1.00E+00	Kg			

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
Cl2	Kg/kg Phosgen	1.41667E-05		Kg/kg Phosgen	1.41667E-05		5
CO	Kg/kg Phosgen	5.59634E-06		Kg/kg Phosgen	5.59634E-06		5
Phosgene	Kg/kg Phosgen	5.55556E-07		Kg/kg Phosgen	5.55556E-07		5

HCl	Kg/kg Phosgen	5.55556E-07	Kg/kg Phosgen	5.55556E-07	5

Water

Solid Wastes

Resource Consumption

CO	Kg/kg Phosgen	0.23	Kg/kg Phosgen	0.23
Cl2	Kg/kg Phosgen	0.72	Kg/kg Phosgen	0.72
Activated Carbor	Kg/kg Phosgen	0.0005	Kg/kg Phosgen	0.0005

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Mw Benzen	78.1134
Mw Chlorin	70.9
Mw ClBz	112.56
Mw Cl2Bz	147.01
Mw HCl	36.4609
Mw NaOH	39.9971

molar dry air composition		Mwt	mass composition	kg air per kg component
N2	0.78084	28.0134	0.75521	1.324134
O2	0.20946	31.9988	0.231406	4.321406
CO2	0.00033	44.01	0.000501	1994.319
Ar	0.00934	39.948	0.012882	77.62792
total	0.99997	28.96409	1	

Ideal gas density at 15 C (60 F) air (dry)

	0.042296 mol/liter	42.29634021 mol/m^3	1.225075005 kg/m^3
Calculations			

Phosgene Production 1993

Source: None

Phosgene production capacity

Source: SRI 1991 Directory of Chemical Producers, US

	Mlb	2290	
Utilization ratio:	chemical industry average 199	0.9	
		Capacity Mlb	Calculated production: Mlb
Van de Mark Chemical Com	Lockport, NY 14094	20	18
Olin Corporation	Lake Charles, LA 70602	254	228.6
BASF Corporation	Geismar, LA 70734	320	288
Miles Inc.	Baytown TX 77520	450	405

Source: Emissions:
TRI database, 1993 data
The Van de Mark plant is the only manufacturer of phosgene for open sale on the market so only its TRI data are used

The following reported emissions were ascribed to Phosgene production o

		Phosgene	Chlorine	Carbon monoxide	HCl
Van de Mark Chemical Com	Lockport, NY 14094	5.56E-07	1.42E-05		5.56E-07
Olin Corporation	Lake Charles, LA 70602	1.71E-07	1.30E-04		2.42E-05
BASF Corporation	Geismar, LA 70734	2.43E-08	7.29E-08		2.57E-04
Miles Inc.	Baytown TX 77520	6.30E-07	1.98E-05		1.06E-05
		1.133333333	1.394335512		9.84265E-06

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg Phosgen	0			MJ/kg Phosgene	0	
Coal	MJ/kg Phosgen	0			Kg/kg Phosgene	0	
Oil	MJ/kg Phosgen	0			Kg/kg Phosgene	0	
Natural Gas	MJ/kg Phosgen	0			Kg/kg Phosgene	0	
Hydropower	MJ/kg Phosgen	0					
Fission	MJ/kg Phosgen	0					
Electricity (generic)	MJ/kg Phosgen	0.375737838			MJ/kg Phosgene	0.375737838	

Cooling
water

25 deg C temp rise
0.104482 heat removal MJ/kg water 0.004179285 heat capacity MJ/Kg/deg C (see pCl3 sheet)

	0.263016 MJ/kg product	6224.3 D Hvap CCl2Ocal/mol	0.263016316 MJ/Kg phosgene		
c water	2.517333 Kg/Kg product		0.375737595 Refrigeration electricity usage fo		0.7 efficiency

7.87E-05 kJ Elec/Kg — Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

		representative m	Sp grav	Sp visc	kgflow/kg prod		
condenser	to storage	Phosgene	1.392	1.5	MJ/kg Phosgen	1.6438E-07	viscosity is a guess
distillation	to treatmen	Phosgene solutio	1	1	Chlorine	7.8726E-08	viscosity is a guess
cooling water			1	1	2.517332912	0	
						2.43106E-07	total pumping energy per kg prod

Co-Products:

source: See from above

Resources: Faith, Keyes and Clark'e Industrial chemicals

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Oil	Kg/kg Phosgen	0		4	Kg/kg Phosgene	0	
	Natural Gas	Kg/kg Phosgen	0		4	Kg/kg Phosgene	0	
	Coal	Kg/kg Phosgen	0		4	Kg/kg Phosgene	0	
28.0104	CO	m^3/kg Phosge	0.23		4	Kg/kg Phosgene	0.23	
70.906	Cl2	Kg/kg Phosgen	0.72		4	Kg/kg Phosgene	0.72	
12.011	Activated Carbon	Kg/kg Phosgen	0.0005		4	Kg/kg Phosgene	0.0005	
	Air	Kg/kg Phosgen	0		4	Kg/kg Phosgene	0	
	Water	Kg/kg Phosgen	0		4	Kg/kg Phosgene	0	

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.	
TSP	Kg/kg Phosgen	0			Kg/kg Phosgene	0		
SOx	kg/kg Phosgen	0			Kg/kg Phosgene	0		
NOx	kg/kg Phosgen	0			Kg/kg Phosgene	0		
Cl2	kg/kg Phosgen	1.42E-05			Kg/kg Phosgene	1.41667E-05		
CO2	kg/kg Phosgen	0		3	Kg/kg Phosgene	0		
CO	kg/kg Phosgen	5.59634E-06			Kg/kg Phosgene	5.59634E-06		Industrial practice is to leave excess
Phosgene	kg/kg Phosgen	5.56E-07			Kg/kg Phosgene	5.55556E-07		
HCl	kg/kg Phosgen	5.56E-07			Kg/kg Phosgene	5.55556E-07		
HC total	kg/kg Phosgen	0			Kg/kg Phosgene	0		
Heavy meta(Cd+Ni+Cr)	kg/kg Phosgen	0			Kg/kg Phosgene	0		

Water

Raw/	Raw/	Raw/	Transformed	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
COD	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
BOD	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
Acid, H+ (Phosphoric)	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
Metal ions	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
Cl2	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
CO2	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
CO	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
Phosgene	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
HCl	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
Heavy metals (Cadmium, Ni	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	
Heavy metals (Cadmium, Ni	kg/kg Phosgen	0		5	Kg/kg Phosgene	0	

Sheet End

Sheet Title: Ammonia (data for fertilizer production, applied to nitric acid production)

Sheet Description: This page calculates the vendor-independent emissions from US plants producing fertilizer quality Ammonia. Oil and Natural gas extraction and transportation are not included.

References/Citations:

U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
Ammonia	1.00E+00	kg
Total	1	kg

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components

		Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
	Air							
	TSP (PM-10)	Kg/Kg Ammon	5.90939E-10		kg/kg TNAZ			4
	SOx	Kg/Kg Ammon	2.88E-05		kg/kg TNAZ			4
	NOx	Kg/Kg Ammon	6.13238E-09		kg/kg TNAZ			4
	CO	Kg/Kg Ammon	0.007900001		kg/kg TNAZ			4
	CO2	Kg/Kg Ammon	1.2234		kg/kg TNAZ			4
	Ammonia	Kg/Kg Ammon	0.0021		kg/kg TNAZ			4
	Methane	Kg/Kg Ammon	7.47036E-10		kg/kg TNAZ			4
	other organic	Kg/Kg Ammon	0.004720003		kg/kg TNAZ			4
	Water							
	Solid Wastes							
	Resource Consumption							
	Natural Gas	Kg/Kg Ammon	0.549481458					4
fuel	Natural Gas	Kg/Kg Ammon	0.5057511					4
	Electric Power	MJ/kg Ammon	1.1					4
	steam	MJ/kg Ammon	0.38					4

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Table 35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers

U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

	lb/ton of ammonia produced				
Emission Source	CO	SO2	NH3	CO2	Total Organic Compounds
Desulferization Unit	13.8	0.0576			7.2
Carbon Dioxide Regenerator	2		2	2,440	1.04
Condensate Steam Stripper			2.2	6.8	1.2
Total	15.8	0.0576	4.2	2446.8	9.44
In units of	Kg/Kg ammonia				
Total	0.0079	0.0000288	0.0021	1.2234	0.00472

Notes: Since we know the amount of methane (and hence carbon) used as a feedstock for Ammonia production one can calculate a bound on process related CO2 emissions.

Feedstock Methane Use	21.78	million btu/ton ammonia	0.024008094	million btu/kg ammonia
	26.48222965	million btu/ton N	1.055232558	kg/ kg Ammonia
	13241.11482	Btu/lb N		
Carbon per unit Methane	14.47	Million metric tons C/quad		
	31.900562	lb C/million btu		
	116.8876325	lb CO2/million btu		
	1.547722563	lb CO2/lb N		
	3095.445126	lb CO2/ton N		

This shows that the CO2 emission factors for process related emissions are based on the carbon value of the feedstock, and the assumption that virtually all carbon is emitted, not used for other purposes.

Emissions from Energy Consumption in Ammonia Manufacture

Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Energy for Nonfuel Purposes (MECS Table A3)

Nitrogenous Fertilizers	Raw Input Quantity	Units	Transformed Input Quantity	Units	Notes:
Natural Gas	289	Tbtu	52.07%	Feedstock Share	
Total	290	Tbtu			

Energy for Heat, Power, etc. (MECS Table A4)

Natural Gas	266	Tbtu	0.479279279	Fuel Share
Electricity	10	Tbtu		
Other	4	Tbtu		

Total Primary Energy Consumption (MECS Table A1)

Natural Gas	555	Tbtu
Electricity	10	Tbtu
Other	568	Tbtu

Large Industrial Boiler Emission Factors (AP-42, Tables 1.4-1 to 1.4-3)
Natural gas powered heat source

SO2		0.6	lb/million cubic ft	0.00058	lb/million btu	
NOx	Uncontrolled	550	lb/million cubic ft	0.53295	lb/million btu	
	Controlled-Lo NOx	81	lb/million cubic ft	0.07849	lb/million btu	
	Controlled-FGR	53	lb/million cubic ft	0.05136	lb/million btu	
	Average Controlle	67	lb/million cubic ft	0.06492	lb/million btu	
	Average	308.5	lb/million cubic ft	0.29893	lb/million btu	
CO		40	lb/million cubic ft	0.03876	lb/million btu	
PM-10		13.7	lb/million cubic ft	0.01328	lb/million btu	This factor is given as the sum of filterable and condensible particulate. All PM emissions from N.G. consumption are thought to be < 10 microns in diameter
Methane		0.289	lb/million cubic ft	0.00028	lb/million btu	
Non-methane VOC's		1.41	lb/million cubic ft	0.00137	lb/million btu	
CO2		14.47	million metric ton	116.9	lb/million btu	
Heat Content of Natural Gas (AER, Table A		1,032	Btu/cubic foot			

Emissions from the Use of N.G. in the Manufacture of Ammonia

SO2	6.69E-12	kg/kg ammonia
NOx	6.13E-09	kg/kg ammonia
CO	9.03E-10	kg/kg ammonia
PM-10	5.91E-10	kg/kg ammonia
Methane	7.47E-10	kg/kg ammonia
Non-methane VOC's	3.44E-09	kg/kg ammonia
CO2	4.46E-10	kg/kg ammonia

Notes: The share of N.G. used as feedstock for Ammonia vs. fuel is used to reduce emissions estimates to account for N.G. not consumed in boilers.

Emission factors are converted into units of lb/million btu, which are multiplied by energy consumption and share of energy used as fuel.
Emissions from the consumption of electricity by the industry will be calculated by the electricity module.

N.G. is used as a feedstock through a reforming process to produce hydrogen gas. This is the predominant process for ammonia production in the U.S.
The hydrogen is reacted with nitrogen to form ammonia. This process results in the production of carbon dioxide and carbon monoxide.
Carbon monoxide can be converted back to carbon dioxide through the water-gas shift reaction. Carbon dioxide has
industrial use in several areas including the manufacture of urea from ammonia,
but some carbon dioxide is emitted from the process. These and other process related emissions are treated in Table 25.

Source:
Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited,
Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program
Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

Energy Requirements for Fertilizer Production

	Natural Gas	Electricity	Oil	Steam	Exported Steam	Total	
Anhydrous Ammonia	40.79	1.1	0	0	0.38	41.51	(GJ/metric ton)
	38693.394	1043.46	0	0	360.468	39376.386	Btu/kg
	kg/kg Ammonia	MJ/kg Ammonia					
	17.00698487	1.1					

Notes: Taken from Table 16 (p. 26).

Unit from	Unit to	Multiplier	Name	Source:		
bu	lb	56	lb_bu			
Hectares	acre	2.471	acre_hect			
kg	lb	2.2046	lb_kg			
hectares	sq. meters	10,000	sqmeters_hect			
meter	feet	3.281	feet_meter			
short tons	lb	2000	lb_shortton			
metric tons	kg	1000	kg_mton			
kcal	btu	3.968	btu_kcal			
Joules	btu	9.49E-04	btu_joule			
Gallons Ethanol	lb	6.6	lb_gallon			
Gallons Ethanol	bu	0.4	bu_gallon			
Hectares	Sq. cm	1.00E+08	sqcm_ha			
cubic cm	liters	0.001	liters_ccm			
liters	gallons	0.264	gallons_liter			
sq mile	acres	640	acres_sqmile			
metric tons	short tons	1.102	shortton_metricton			
barrels	gallons	42	gallons_barrel		0	
kg	grams	1,000	grams_kg			
cubic foot natural g	btu	1,032	btu_cubicft		0	
barrel distillate fue	million btu	5.825	btu_barreloil		0	138,690
barrel motor gasol	million btu	5.253	btu_barrelgas		0	125,071
Short ton coal	million btu	22.25	Btu_toncoal		0	
Barrel LPG	million btu	3.614	Btu_barrellpg			86,048

Molecular Wts.

H	1.008
Ca	40.08
O	16.00
S	32.06
C	12.01
Cl	35.45
K	39.10
P	30.97
N	14.01
K2O	94.20
KCl	74.56
CO2	44.01
CaSO4	136.14
H2SO4	98.07
P2O5	141.94
HNO3	63.01
NH4NO3	80.04

Sheet Title: soda caustic

Sheet Description: This page calculates the vendor-independent emissions from european manufacture of caustic soda .

References/Citations: SimaPro3 (entry of Nov 18 94)
Average european data for NaOH/Cl2 producers.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 6, tbl 15 pg 13 and report 5 (allocation)

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units	
NaOH	1.00E+00	Kg	
Chlorine			data after allocation
Total	1	Kg	

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
COD	Kg/Kg soda caus	0.074					3
BOD	Kg/Kg soda caus	0.00002					3
Acid as H+	Kg/Kg soda caus	0.007					3
Nitrate	Kg/Kg soda caus	0.0008					3
Metal ions	Kg/Kg soda caus	1.21					3
Cl2	Kg/Kg soda caus	0					3
ammonia	Kg/Kg soda caus	0.00018					3
dissolved organi	Kg/Kg soda caus	0.006					3
Crude	Kg/Kg soda caus	0.000002					3
dissolved substa	Kg/Kg soda caus	0.00005					
HC's	Kg/Kg soda caus	0					
unknown (N)	Kg/Kg soda caus	0.0028					
Water							
COD	Kg/Kg soda caus	0.00001					3
BOD	Kg/Kg soda caus	0.000003					3
Acid as H+	Kg/Kg soda caus	0.00034					3
Metal ions	Kg/Kg soda caus	0.00009					3

	Cl2	Kg/Kg soda caus	0.042		3
	Dissolved Organ	Kg/Kg soda caus	0		3
	suspended solid	Kg/Kg soda caus	0.002		3
	crude oil	Kg/Kg soda caus	0		3
	miscelanious dis	Kg/Kg soda caus	0.00005		3
	total HC's	Kg/Kg soda caus	0		
	sodium	Kg/Kg soda caus	0.0028		3
	Solid Wastes				
	Production waste	Kg/Kg soda caus	0.099		3
Resource Consumption					
fuel	Natural Gas	Kg/Kg soda caus	0.176505121	6766029.629	3
fuel	Crude Oil	Kg/Kg soda caus	0.129783177	23.09245495	3
	Coal	Kg/Kg soda caus	0		
fuel	Coal	MJ/Kg soda caus	0.217294119	38.66336743	3
	Hydropower	MJ/Kg soda caus	0.734851726		
	Fission		5.940913952		
	Iron ore	Kg/Kg soda caus	0.00046		
	limestone	Kg/Kg soda caus	0.0105		
	Rock salt	Kg/Kg soda caus	0.59		
	Water	Kg/Kg soda caus	5.3		
	sand		0.00002		

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
		1055.056	
BTU	J	3600	CRC, 66th Edition
Wh	J	5800000	CRC, 66th Edition
bbl CrO	BTU CrO	42	Chemical Engineers' Handbook, 6th ed.
bbl	gal	118500	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	3.785412	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal	L	2.2046226	CRC, 66th Edition
kg	lb	365	CRC, 66th Edition
yr	day	6.289811	
m^3	bbl (petroleum)	7.2	CRC, 66th Edition
gal CrO	lb CrO	2000	
ton	lb	138000	
gal fuel oil	BTU fuel oil	1032	

cu. ft NG	BTU NG	12000	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)	BTU Coal	46	calculation page B	SD=11%
kg NG	MJ NG		Calculated page C	SD=13%

Calculations

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	1 Kg						
soda caustic (polymer)				3			
soda caustic (other)							
						0	

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality soda caustic.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	MJ/Kg soda caus						
Coal	MJ/Kg soda caus	5.86		3	Kg/Kg soda caustic	0.217294119	
Oil	MJ/Kg soda caus	3.5		3	Kg/Kg soda caustic	0.129783177	
Natural Gas	MJ/Kg soda caus	4.76		3	Kg/Kg soda caustic	0.176505121	
Hydropower	MJ/Kg soda caus	0.71		3	MJ/Kg soda caustic	0.734851726	
Fission	MJ/Kg soda caus	5.74		3	MJ/Kg soda caustic	5.940913952	
unspecified		0.72					

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	MJ/Kg soda caus						
Oil	MJ/Kg soda caus	0		3	Kg/Kg soda caustic	0	
Natural Gas	MJ/Kg soda caus	0		3	Kg/Kg soda caustic	0	
Coal	Kg/Kg soda caus	0		3	Kg/Kg soda caustic	0	
Iron ore	Kg/Kg soda caus	0.00046		3	Kg/Kg soda caustic	0.00046	
limestone	Kg/Kg soda caus	0.0105		3	Kg/Kg soda caustic	0.0105	
Bauxite	Kg/Kg soda caus	0		3	Kg/Kg soda caustic	0	
Rock salt	Kg/Kg soda caus	0.59		3	Kg/Kg soda caustic	0.59	
Clay	Kg/Kg soda caus	0		3	Kg/Kg soda caustic	0	
Water	Kg/Kg soda caus	5.3		3	Kg/Kg soda caustic	5.3	
sand		0.00002		3	Kg/Kg soda caustic	0.00002	

Output

	Raw/ Input Units	Raw/	Raw/		Transformed	Transformed	Transformed
Air							

LCI component	Kg/Kg soda caus	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
TSP	Kg/Kg soda caus	0.074			Kg/Kg soda caustic	0.074	
SOx	Kg/Kg soda caus	0.00002			Kg/Kg soda caustic	0.00002	
NOx	Kg/Kg soda caus	0.007			Kg/Kg soda caustic	0.007	
CO	Kg/Kg soda caus	0.0008			Kg/Kg soda caustic	0.0008	
CO2	Kg/Kg soda caus	1.21			Kg/Kg soda caustic	1.21	
H2S	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
HCl	Kg/Kg soda caus	0.00018			Kg/Kg soda caustic	0.00018	
total HC's		0.006			Kg/Kg soda caustic	0.006	
	Kg/Kg soda caustic						
Heavy metals		0.000002			Kg/Kg soda caustic	0.000002	

Water

LCI component	Raw/ Input Units Kg/Kg soda caus	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg soda caus	0.00001			Kg/Kg soda caustic	0.00001	
BOD	Kg/Kg soda caus	0.000003			Kg/Kg soda caustic	0.000003	
Acid as H+	Kg/Kg soda caus	0.00034			Kg/Kg soda caustic	0.00034	
Nitrate	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
Metal ions	Kg/Kg soda caus	0.00009			Kg/Kg soda caustic	0.00009	
Cl2	Kg/Kg soda caus	0.042			Kg/Kg soda caustic	0.042	
ammonia	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
dissolved organics	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
suspended particles	Kg/Kg soda caus	0.002			Kg/Kg soda caustic	0.002	
Crude	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
dissolved substances	Kg/Kg soda caus	0.00005			Kg/Kg soda caustic	0.00005	
HC's	Kg/Kg soda caus	0			Kg/Kg soda caustic	0	
sodium		0.0028			Kg/Kg soda caustic	0.0028	

Solid waste	Kg/Kg soda caus						
Production waste (not innert)	Kg/Kg soda caus	0.099			Kg/Kg soda caustic	0.099	
Toxic chemicals		0.00002			Kg/Kg soda caustic	0.000001	

	1000 bbl/day						
CrO from Alaska		1798			ton/yr	99228024	
Total					ton/yr	99228024	
	mi						
Water Shipping - Lower 48	mi	0			ton-mi/yr	0	
Water Shipping - Alaska		2439.6			ton-mi/yr	2.42077E+11	

Crude Oil Transport

Association of Oil Pipe Lines Data for 1990

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	mi						
Pipelines	mi	0					
Water	mi	2439.6					
Highway/Motor Carrier	mi	1000					
Rail		697					

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	BTU/ton-mi						
Pipelines	BTU/ton-mi	0					
Water	BTU/ton-mi	361			gal fuel/bbl CrO	0.964936049	

Highway/Motor Carrier	BTU/ton-mi	434			gal fuel/bbl CrO	0.553762025
Rail		434			gal fuel/bbl CrO	0.385972132

Water Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
SOx	lb/1000 gal fuel	27			kg/bbl CrO	0.011817566	
CO	lb/1000 gal fuel	100			kg/bbl CrO	0.043768763	
HC	lb/1000 gal fuel	50			kg/bbl CrO	0.021884382	
NOx	lb/1000 gal hauled	280			kg/bbl CrO	0.122552537	
HC - transfer		0.97			kg/bbl CrO	0.018479353	

Highway Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
HC	lb/1000 gal fuel	5.4572			kg/bbl CrO	0.001370752	
CO	lb/1000 gal fuel	15.3321			kg/bbl CrO	0.003851151	
NOx	lb/1000 gal hauled	18.6622			kg/bbl CrO	0.004687613	
HC - transfer		3.25			kg/bbl CrO	0.061915359	

Railroad Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	lb/1000 gal fuel	25			kg/bbl CrO	0.00437685	
SOx	lb/1000 gal fuel	57			kg/bbl CrO	0.009979219	
CO	lb/1000 gal fuel	130			kg/bbl CrO	0.022759622	
HC	lb/1000 gal fuel	94			kg/bbl CrO	0.016456957	
NOx	lb/1000 gal fuel	370			kg/bbl CrO	0.064777386	
Aldehydes	lb/1000 gal fuel	5.5			kg/bbl CrO	0.000962907	
Organic Acids	lb/1000 gal hauled	7			kg/bbl CrO	0.001225518	
HC - transfer		3.25			kg/bbl CrO	0.061915359	

Sheet End

Sheet Title: Sulfuric Acid (for phosphate wet method production)

Sheet Description: This page calculates the vendor-independent emissions from domestic production of sulfuric acid.
Oil extraction and transportation are not included

References/Citations: U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

The Fertilizer Institute. 1982. The Fertilizer Handbook

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
H2S04	1.00E+00	Kg
Total	1	kg

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components		Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air								
	SOx	Kg/Kg Sulfuric	0.013					4
	CO2	Kg/Kg Sulfuric	0.00405					4
	H2SO4	Kg/Kg Sulfuric	0.000064					4
Water								
Solid Wastes								
Resource Consumption								

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Process Emissions from Sulfuric Acid Manufacture (data for phosphoric acid manufacture, applied to general use: HNO3, ion exchange etc.)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Sulfuric acid is used in the manufacture of many precursors to TNAZ. Emission consist primarily of sulfur dioxide and acid mist. Sulfur dioxide emissions are primarily a function of the conversion efficiency from SO2 to SO3 in the plant.

Emission Factors

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source:	
bu	lb	56	lb_bu		
Hectares	acre	2.471	acre_hect		
kg	lb	2.2046	lb_kg		
hectares	sq. meters	10,000	sqmeters_hect		
meter	feet	3.281	feet_meter		
short tons	lb	2000	lb_shortton		
metric tons	kg	1000	kg_mton		
kcal	btu	3.968	btu_kcal		
Joules	btu	9.49E-04	btu_joule		
Gallons Etha	lb	6.6	lb_gallon		
Gallons Etha	bu	0.4	bu_gallon		
Hectares	Sq. cm	1.00E+08	sqcm_ha		
cubic cm	liters	0.001	liters_ccm		
liters	gallons	0.264	gallons_liter		
sq mile	acres	640	acres_sqmile		
metric tons	short tons	1.102	shortton_metricton		
barrels	gallons	42	gallons_barre	0	
kg	grams	1,000	grams_kg		
cubic foot na	btu	1,032	btu_cubicft	0	
barrel distilla	million btu	5.825	btu_barreloil	0	138,690
barrel motor	million btu	5.253	btu_barrelga	0	125,071
Short ton coa	million btu	22.25	Btu_toncoal	0	
Barrel LPG	million btu	3.614	Btu_barrellpg		86,048

Molecular Wts.

H	1.008
O	16.00
Cl	35.45
K	39.10
CO2	#REF!
CaSO4	#REF!

Conversion Eff. - SO_2 -> SO_3	SO_2 Emissions lb/ton sulfuric	Kg/Kg Sulfuric acid	
93	96	0.048	
94	82	0.041	
95	70	0.035	
96	55	0.0275	
97	40	0.02	
98	26	0.013	<=taken as representative
99	14	0.007	
99.5	7	0.0035	
99.7	4	0.002	
100	0	0	

Notes: Sulfur dioxide emissions are highly correlated with conversion efficiency. Typical conversion efficiencies are given in AP-42 as 95 to 98%. Sufur emissions can be controlled using standard sulfur capture technologies. New Source Performance Standards are also set quite low, at 4 lb/ton of product. Assuming that new plants comply with NSPS limits, but that old plants exist with higher emissions, the emission rate used here is at the upper end of conversion efficiency estimates.

Acid Mist Emission Factors (Where values are given as a range, the midrange is used)

	lb/ton H_2SO_4		kg/Kg Sulfuric acid		
Raw Material	Uncontrolled	Controlled	Uncontrolled	Controlled	
Recovered Sulfur	0.574	-	0.000287		
Elemental Sulfur	-	0.128		0.000064	<=taken as representative
Bright Virgin Sulfur	1.7	-	0.00085		
Dark Virgin Sulfur	3.3	2.06	0.00165	0.00103	
Spent Acid	2.3	0.34	0.00115	0.00017	

Notes: According to AP-42 about 81% of sulfuric acid production is from elemental sulfur burning. Average emission factors are calculated above using the elemental, bright virgin, and dark virgin sulfur factors. The uncontrolled and controlled factors are then averaged.

Carbon Dioxide	8.1	lb/ton sulfuric acid
	0.00405	Kg/Kg Sulfuric acid

Notes: Carbon dioxide emissions are negligible relative to other sources and are thus neglected.

Sheet Title: Chlorobenzenes (mono- for triphenyl posphine production)

Sheet Description: Emissions are from TRI database.
Engineering calculation (rough) of the Energy requirements based on the cooling and distillation needs.
This page calculates the vendor emissions from a plant producing Chlorobenzenes.
Not included are raw material production or extraction or water and energy use.

References/Citations:
Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed, 1991-4
Wiley Interscience,

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output
Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	
112.559	Chlorobenzene	8.85E+07	kg	1.72E+00	kg	
	Not as precursor:	5.15E+07	kg	1.00E+00	kg	
147.091	o-dichlorobenzen	15767000	kg	3.06E-01	kg	derivative of mono-chlorobenzene

147.091	p-dichlorobenzen	32614000	kg	6.34E-01	kg	derivative of mono-chlorobenzene
	trichlorobenzenes		kg		kg	
36.4609	HCl	40660216.8	kg	7.90E-01	Kg	Product of chlorination
	Total	1.41E+08	Kg	2.73E+00	Kg	

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
Cl2	Kg/Kg Chlorob	0.004199242		Kg/Kg Chlorob	0.002442546		3
Benzene	Kg/Kg Chlorob	5.32399E-06		Kg/Kg Chlorob	3.09677E-06		3
HCl	Kg/Kg Chlorob	0.0072757		Kg/Kg Chlorob	0.004232035		3
dichlorobenzenes	Kg/Kg Chlorob	4.31031E-06		Kg/Kg Chlorob	2.50715E-06		3
chlorobenzene	Kg/Kg Chlorob	7.01061E-05		Kg/Kg Chlorob	4.07782E-05		3
Water							
Solid Wastes							
Resource Consumption							
Heat Energy (fos	MJ/Kg Chlorob	4.396342073		MJ/Kg Chlorob	4.396342073		
Electric Power	MJ/Kg Chlorob	2.361E-05		MJ/Kg Chlorob	2.361E-05		
Benzene	Kg/Kg Chlorob	0.693971215		Kg/Kg Chlorob	0.693971215		
Chlorine	Kg/Kg Chlorob	0.629886283		Kg/Kg Chlorob	0.629886283		
Sodium hydroxid	Kg/Kg Chlorob	0.008664743		Kg/Kg Chlorob	0.008664743		

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition

bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Mw Benzen	78.1134	molar				kg air per kg
Mw Chlorin	70.9	dry air composition		Mwt	mass composition	component
Mw ClBz	112.56	N2	0.78084	28.0134	0.75521	1.324134
Mw Cl2Bz	147.01	O2	0.20946	31.9988	0.231406	4.321406
Mw HCl	36.4609	CO2	0.00033	44.01	0.000501	1994.319
Mw NaOH	39.9971	Ar	0.00934	39.948	0.012882	77.62792
		total	0.99997	28.96409	1	

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter — 42.29634021 mol/m^3 — 1.225075005 kg/m^3

Calculations

Chlorobenzene Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg Chlorobe	4.396342073				0.157507219	
Coal	MJ/kg Chlorobe	0			kg/kg Chlorobenze	0	
Oil	MJ/kg Chlorobe	0	15		kg/kg Chlorobenze	0	0.33622909
Natural Gas	MJ/kg Chlorobe	0			kg/kg Chlorobenze	0	
Hydropower	MJ/kg Chlorobe	0					
Fission	MJ/kg Chlorobe	0					

Electricity (generic)	MJ/kg Chlorobe	2.361E-05		Probably different mix in US

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Benzene batch Chlorination method (Cl2 bubbled through)

from Faith Keyes and Clark's Industrial chemicals, 1975

Stoichiometric ratios:

Benzene net	Kg/Kg Chlorob	0.693971215	100%	conversion of Benzene
Cl2 net	Kg/Kg Chlorob	0.629886283		
Benzene input	Kg/Kg Chlorob	0.693971215	100%	conversion of Benzene
Cl2 input - no recycle	Kg/Kg Chlorob	1.049810471	60%	conversion of Cl2
Chlorine input	Kg/Kg Chlorob	0.634085525	99%	Cl2 recovery - assumed, because of bubbling apparatus

Emission calculation

Air

Cl2 released from process	Kg/Kg Chlorob	0.004199242	1%	Uncoverted Cl2
HCl released	Kg/Kg Chlorob	0.0072757		released in scrubber vent see calculation
CO2	Kg/Kg Chlorob	0		
Particulates	Kg/Kg Chlorob	0		
Benzene	Kg/Kg Chlorob	5.32399E-06		open neutralizer vent
mono Chlorobenzene	Kg/Kg Chlorob	7.01061E-05		
o dichlorobenzene	Kg/Kg Chlorob	4.31031E-06		
p dichlorobenzene	Kg/Kg Chlorob	0		
SOx	Kg/Kg Chlorob	0		
NOx	Kg/Kg Chlorob	0		
Heavy metals	Kg/Kg Chlorob	0		

HCl emission calculation

Vapor pressure of 1mmHg over water solution 20%

Open scrubber assumed to equilibrate so that vapor containing 1/760 parts volume HCl is displaced from the scrubbing chamber by the incoming water/HCl stream 20% HCl

7.90E-01 Kg HCl produced/Kg Chlorobenzene

HCl sol. density kg/m^3(roug	1100	3.949340383	Kg HCl stream
HCl partial pressure mmHg	1 CRC 66	0.0072757	Kg HCl (1/760)
Overall pressure (atm) mmH	761 CRC 66		

Benzene Emissions calculation

Vapor pressure at condenser vent assumed to be at 25 degC							Raoult's law	Kg emission/Kg prod
Composition (mol%)				wt%			vapor composition	
Bz 99% con	78.11	0.01	0.781134	0.006315964	Bz	100 mmHg	0.00131406	5.32E-06
ClBz	112.56	0.7	78.792	0.637083303	ClBz	13.05454545 mmHg	0.012008123	7.01E-05
Cl2Bz-o	147.01	0.2	29.402	0.237733822	Cl2Bz-o	2.150895141 mmHg	0.000565281	4.31E-06
Cl2Bz-p	147.01	0.1	14.701	0.118866911	Cl2Bz-p solid a	0 mmHg	0	0
Source: FKC 75 4ed			123.676134		CRC 66 interpolated			

vapor displacement by chlorobenzine product/kg mono ClB	0.00122629	m^3	0.051867653	mol gas displaced/kg ClBz
density of ClBz at end of react	1,280.00	kg/m^3		

Co-Products:
source: See from above

Resources:

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil					Kg/Kg Chlorobenzene		
Natural Gas					Kg/Kg Chlorobenzene		
Coal	Kg/Kg Chlorob	0		3	Kg/Kg Chlorobenz	0	
Iron ore	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Benzene	Kg/Kg Chlorob	0.693971215		3	Kg/Kg Chlorobenz	0.693971215	
Chlorine	Kg/Kg Chlorob	0.629886283			Kg/Kg Chlorobenz	0.629886283	
Sodium hydroxide (dry bassi	Kg/Kg Chlorob	0.008664743			Kg/Kg Chlorobenz	0.008664743	
Clay	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	

Water

Raw/	Raw/	Raw/	Transformed	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
COD	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
BOD	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Acid as H+	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Metal ions	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Cl2	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Dissolved Organics	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
suspended solids	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
crude oil	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
miscelanious dissolved mate	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	
Phenol	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert)	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0.00128	
Toxic chemicals	Kg/Kg Chlorob	0			Kg/Kg Chlorobenz	0.000001	
Ash	Kg/Kg Chlorob	0					

Sheet End

1993																		
8.85E+07		kg	mono chlorobenzene															
48381000		kg	dichlorobenzenes															
Capacities	production				DHfo	DHrx (synthesis)			Refrigeration	water flow		pump for co	material pun	Distillation		pump for co	Elec total	Heat total
Mlb					kcal/mol	kcal/mol	kJoules/kg prod		Heat consump	m^3/kg prod		kJ Elec/Kg p	kJ Elec/Kg p	kJ/kg prod	m^3/kg prod	kJ Elec/Kg p	kJ Elec/Kg p	kJ/kg prod
									kJ/kg prod									
50	15767000 o		dichlorobenzenes		39.995	-13.839	-393.5171	from mono	605.410989	0.1649158	1011.6387	0.0129832	0.0005511					
75	32614000 p		dichlorobenzenes		39.995	-13.839	-393.5171	from mono	605.410989	0.1649158	2092.572	0.0129832	0.0005511					
150	8.85E+07	mono	mono chlorobenzene		13.882	-13.839	-513.9216	from benzen	790.64868	0.2153751	7415.7123	0.0169556	0.0005511	3605.6934	0.0775256	0.0061033	0.02361	4396.3421
			HCl		-39.952				65% efficiency									
			Benzene		-12.231								7 pumping stages per material					
									42.8	Btu/ton*min								
									45.15828	kJ/ton*min								
								water requir	3.25	gal water/ton*min		0.078726	kJ Elec/m^3					
									0.0002724	m^3/kJ		7.873E-05	kJ Elec/Kg					
									250	ft representative head value				cooling value of water				
			separations						65%	heat removal efficiency				19.99683	Btu/lb			
			Distill mono from 75% to 100% with 10% heavy, 10% light						150/371	production factor for plant				46.509688	kJ/kg			
									40 hr week									
			minimum energy						52 week year									
			10% of vaporization heat * recycle						77.50%	pump efficiency								
						DHvap	KJ/Kg	btu/lb	KJ/Kg									
			Heat	126.3	Btu req	cal/mol		1403.3333	3263.94704	both								
			Cool	118.9	Btu req			4210	9791.84113	light								
	92.15	110.6		0.06	toluene	9368.5	425.65576		12.3968043									
	78.54	80.1	Medium/Eas	0.03	benzene	10254	548.73537											
				0.01	waste	?												
			Heat	405.9	Btu req	cal/mol		162.36	377.625493	both								
			Cool	260.1	Btu req			4059	9440.63733	light								
	104.16	145.2		2.4	styrene	9634.7	437.7505		1.99812103									
	87.613333	100.43333		0.1	Bz&tol	9301.3	497.75232											
				0.01	waste	?												
			Heat	1308.2	Btu req	cal/mol		551.98312	1283.8316	both								
			Cool	1318.9	Btu req			998.62595	2322.65717	light								
	104.16	145.2		1.06	styrene	9634.7	437.7505		18.0344903									
	106.17	136.2		1.31	ethylBz	9301.3	497.75232											
				0.01	waste	?												
			Heat	1023.1763	Btu req													
			Cool	1318.9	Btu req			1162.7003	2704.27004	3605.6934								
	147.01	180.5		0.12	Cl2Bz-o	10098	458.80043		4									
	112.56	132	17611	0.88	ClBz	10943	497.19283											
	147.01	174			Cl2Bz-p	10611												
	147.01	173			Cl2Bz-m													

Sheet Title: benzene (for chemical and styrene monomer production)

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing technical quality benzene
Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking fascilities producing monomer quality ethylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 4, tbl 12 pg 10

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
benzene	1.00E+00	Kg
Total	1	Kg

LCI components		Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air								
	COD	Kg/Kg benzene	0.0009					3
	BOD	Kg/Kg benzene	0.003					3
	Acid as H+	Kg/Kg benzene	0.0068					3
	Nitrate	Kg/Kg benzene	0.0006					3
	Metal ions	Kg/Kg benzene	0.54					3
	Cl2	Kg/Kg benzene	0.000005					3
	ammonia	Kg/Kg benzene	0.00015					3
	dissolved organi	Kg/Kg benzene	0.0083					3
	Crude	Kg/Kg benzene	0.000001					3
	dissolved substa	Kg/Kg benzene	0.00054					
	HC's	Kg/Kg benzene	0.00008					
	unknown (N)	Kg/Kg benzene	0.000001					
Water								
	COD	Kg/Kg benzene	0.0002					3
	BOD	Kg/Kg benzene	0.00002					3
	Acid as H+	Kg/Kg benzene	0.00004					3
	Metal ions	Kg/Kg benzene	0.00036					3

	Cl2	Kg/Kg benzene	0.00009		3
	Dissolved Organ	Kg/Kg benzene	0.000015		3
	suspended solid	Kg/Kg benzene	0.00012		3
	crude oil	Kg/Kg benzene	0.0001		3
	miscelanious dis	Kg/Kg benzene	0.00054		3
	total HC's	Kg/Kg benzene	0.00008		
	Phenol	Kg/Kg benzene	0.000001		3
	Solid Wastes				
	Production waste	Kg/Kg benzene	0.00966		3
Resource Consumption					
	Natural Gas	Kg/Kg benzene	0.786521739	30150000	3
fuel	Natural Gas	Kg/Kg benzene	0.159347826	6108333.333	#VALUE!
	Crude Oil	Kg/Kg benzene	0.624041192	111.0362948	#VALUE!
fuel	Crude Oil	Kg/Kg benzene	0.031605534	5.623605447	#VALUE!
	Coal	Kg/Kg benzene	0.000358269		
fuel	Coal	Kg/Kg benzene	0.022929203	4.079816828	3
	Hydropower	MJ/Kg benzene	0.07		
	Fission	MJ/Kg benzene	0.2		
	Iron ore	Kg/Kg benzene	0.00015		
	limestone	Kg/Kg benzene	0.00011		
	Bauxite	Kg/Kg benzene	0.00022		
	Rock salt	Kg/Kg benzene	0.0058		
	Clay	Kg/Kg benzene	0.00002		
	Water	Kg/Kg benzene	2.209		

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition

gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Calculations

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI		Transformed Units	Transformed Quan.	Transformed Std. Dev.
benzene (polymer)	1 Kg				3			
benzene (other)								
							0	

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality benzene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI		Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg benzene	0.64			3	Kg/Kg benzene	0.022929203	
Oil	MJ/Kg benzene	1.41			3	Kg/Kg benzene	0.031605534	
Natural Gas	MJ/Kg benzene	7.33			3	Kg/Kg benzene	0.159347826	
Hydropower	MJ/Kg benzene	0.07			3	MJ/Kg benzene	0.07	
Fission	MJ/Kg benzene	0.2			3	MJ/Kg benzene	0.2	
							Probably different mix in US	

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI		Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg benzene	27.84			3	Kg/Kg benzene	0.624041192	
Natural Gas	MJ/Kg benzene	36.18			3	Kg/Kg benzene	0.786521739	
Coal	MJ/Kg benzene	0.01			3	Kg/Kg benzene	0.000358269	
Iron ore	Kg/Kg benzene	0.00015			3	Kg/Kg benzene	0.00015	
limestone	Kg/Kg benzene	0.00011			3	Kg/Kg benzene	0.00011	
Bauxite	Kg/Kg benzene	0.00022			3	Kg/Kg benzene	0.00022	
Rock salt	Kg/Kg benzene	0.0058			3	Kg/Kg benzene	0.0058	
Clay	Kg/Kg benzene	0.00002			3	Kg/Kg benzene	0.00002	
Water	Kg/Kg benzene	2.209			3	Kg/Kg benzene	2.209	

Output
Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg benzene	0.0009			Kg/Kg benzene	0.0009	
SOx	Kg/Kg benzene	0.003			Kg/Kg benzene	0.003	
NOx	Kg/Kg benzene	0.0068			Kg/Kg benzene	0.0068	
CO	Kg/Kg benzene	0.0006			Kg/Kg benzene	0.0006	
CO2	Kg/Kg benzene	0.54			Kg/Kg benzene	0.54	
H2S	Kg/Kg benzene	0.000005			Kg/Kg benzene	0.000005	
HCl	Kg/Kg benzene	0.00015			Kg/Kg benzene	0.00015	
total HC's	Kg/Kg benzene	0.0083			Kg/Kg benzene	0.0083	
Heavy metals	Kg/Kg benzene	0.000001			Kg/Kg benzene	0.000001	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg benzene	0.0002			Kg/Kg benzene	0.0002	
BOD	Kg/Kg benzene	0.00002			Kg/Kg benzene	0.00002	
Acid as H+	Kg/Kg benzene	0.00004			Kg/Kg benzene	0.00004	
Nitrate	Kg/Kg benzene	0.000001			Kg/Kg benzene	0.000001	
Metal ions	Kg/Kg benzene	0.00036			Kg/Kg benzene	0.00036	
Cl2	Kg/Kg benzene	0.00009			Kg/Kg benzene	0.00009	
ammonia	Kg/Kg benzene	0.00009			Kg/Kg benzene	0.00009	
dissolved organics	Kg/Kg benzene	0.000015			Kg/Kg benzene	0.000015	
suspended particles	Kg/Kg benzene	0.00012			Kg/Kg benzene	0.00012	
Crude	Kg/Kg benzene	0.0001			Kg/Kg benzene	0.0001	
dissolved substances	Kg/Kg benzene	0.00054			Kg/Kg benzene	0.00054	
HC's	Kg/Kg benzene	0.00008			Kg/Kg benzene	0.00008	
unknown (N)	Kg/Kg benzene	0.000001			Kg/Kg benzene	0.000001	

Solid waste							
Production waste (not innert)	Kg/Kg benzene	0.00966			Kg/Kg benzene	0.00966	
Toxic chemicals	Kg/Kg ethylene	0.000001			Kg/Kg ethylene	0.000001	

Sheet End ========= ============ ============ ============ ============ ============ =============== ============ ============ ========= ========= =========

Coal type	MoistureSulfur			Heat value				
	%	%	%dry	Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11122			
HV bit A	2.9	0.6	0.62	14170	14593	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352			
Brown CGerman	55	0.3	0.67	4830	10733			
Sub bit A	13.9	0.6	0.70	10330	11998	SD=	1296	0.108
Meta Anthracite	9	0.7	0.77	10080	11077	Avg=	11979	
LV bit	2.9	0.8	0.82	14400	14830	median		
Anthracite	4.3	0.8	0.84	12880	13459			
Lignite	36.8	0.9	1.42	7000	11076			
MV bit	2.4	1.5	1.54	14490	14846			
Semi anthracite	2.1	1.7	1.74	13700	13994			
HV bit B	6.7	2.6	2.79	12390	13280			
HV bit C	15.4	2.9	3.43	10740	12695			

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

Natural gas

	Mwt	heat valu	Rio Arrib	Terrell, T	Stanton,	San Jua	Olds Fie	Cliffside, Texas	avg	SD (rel)
mol%		MJ/M^3								
Methane	16.04	37.57	96.91	45.64	67.56	77.28	52.34	65.8		
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8		
propane	44.1	93.6	0.19		3.18	5.83	0.14	1.7		
butane	58.12	121	0.05		1.42	2.34	0.16	0.8		
pentane	72.15	148.8	0.02		0.04	1.18	0.41	0.5		
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22			
H2S	34.08	23.7		0.01			35.79			
N2	28.01	0	0.68	0.21	21.14	1.39	2.53	25.6	avg	SD (rel)
Mol wt:			16.63	31.18	20.92	21.28	25.49	20.45	19.61	10.79%
heating	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7	39.77	12.81%
	MJ/KG		50.66	12.43	37.37	49.25	26.36	33.63	45.76	13.03%
	0.0224M^3/mol			too high CO2 content for use			too high Sulfur content	too low heating value(?)		

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1050

Synopsis of table 9-14

	Mwt	heat valu	Baltimor	Columbu	Houston	Burming	Washing	Phoenix	avg	SD (rel)
mol%		MJ/M^3	Md	Ohio	Tx	Al	DC	Az		
Methane	16.04	37.57	94.4	93.14	92.5	93.14	95.15	87.37		
ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11		
propane	44.1	93.6	0.6	0.66	2	0.67	0.63	2.26		
butane	58.12	121	0.5	0.22	0.3	0.32	0.24	0.13		
pentane	72.15	148.8	0	0.09	0	0.12	0.05	0		
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61		
H2S	34.08	23.7		0.01						
N2	28.01	0	0.5	0.21	21.14	2.14	0.42	1.37	avg	SD (rel)
Mol wt:			17.13	16.94	23.38	17.33	16.96	18.18	18.32	15.84%
heating	MJ/M^3		39.2	38.34	38.46	38.2	38.87	39.95	38.84	1.10%
	MJ/KG		51.27	50.71	36.84	49.37	51.32	49.22	48.12	13.30%

0.0224M^3/mol

Sheet Title: Chlorine

Sheet Description: This page calculates the vendor-independent emissions from european manufacture of chlorine gas.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average european data for NaOH/Cl2 producers.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 6, tbl 15 pg 13 and report 5 (allocation)

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units	
chlorine	1.00E+00	Kg	
NaOH			data after allocation
Total	1	Kg	

	LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
	Air							
	Water							
	COD	Kg/Kg chlorine	0.00001					3
	BOD	Kg/Kg chlorine	0.000003					3
	Acid as H+	Kg/Kg chlorine	0.00034					3
	Metal ions	Kg/Kg chlorine	0.00009					3
	Cl2	Kg/Kg chlorine	0.042					3
	suspended solid	Kg/Kg chlorine	0.002					3
	miscelanious dis	Kg/Kg chlorine	0.00005					3
	sodium	Kg/Kg chlorine	0.0028					3
	Solid Wastes							
	Production waste	Kg/Kg chlorine	0.099					3
	Resource Consumption							
fuel	Natural Gas	Kg/Kg chlorine	0.088043478			3375000		3
fuel	Crude Oil	Kg/Kg chlorine	0.079350065			14.11883921		3

fuel	Coal	Kg/Kg chlorine	0.242547977	43.15681238	3
	Hydropower	MJ/Kg chlorine	0.72		
	Fission	MJ/Kg chlorine	6.14		
	Iron ore	Kg/Kg chlorine	0.00065		
	limestone	Kg/Kg chlorine	0.0186		
	Rock salt	Kg/Kg chlorine	1.21		
	Water	Kg/Kg chlorine	0.9		
	sand	Kg/Kg chlorine	0.00002		

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Calculations

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
chlorine (polymer)	1 Kg			3			
chlorine (other)							
						0	

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality chlorine.
taken from:

PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg chlorine	6.77		3	Kg/Kg chlorine	0.242547977	
Oil	MJ/Kg chlorine	3.54		3	Kg/Kg chlorine	0.079350065	
Natural Gas	MJ/Kg chlorine	4.05		3	Kg/Kg chlorine	0.088043478	
Hydropower	MJ/Kg chlorine	0.72		3	MJ/Kg chlorine	0.72	
Fission	MJ/Kg chlorine	6.14		3	MJ/Kg chlorine	6.14	

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg chlorine	0		3	Kg/Kg chlorine	0	
Natural Gas	MJ/Kg chlorine	0		3	Kg/Kg chlorine	0	
Coal	MJ/Kg chlorine	0		3	Kg/Kg chlorine	0	
Iron ore	Kg/Kg chlorine	0.00065		3	Kg/Kg chlorine	0.00065	
limestone	Kg/Kg chlorine	0.0186		3	Kg/Kg chlorine	0.0186	
Bauxite	Kg/Kg chlorine	0		3	Kg/Kg chlorine	0	
Rock salt	Kg/Kg chlorine	1.21		3	Kg/Kg chlorine	1.21	
Clay	Kg/Kg chlorine	0		3	Kg/Kg chlorine	0	
Water	Kg/Kg chlorine	0.9		3	Kg/Kg chlorine	0.9	
sand	Kg/Kg chlorine	0.00002		3	Kg/Kg chlorine	0.00002	

Output
Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg chlorine	0.0035			Kg/Kg chlorine	0.0035	
SOx	Kg/Kg chlorine	0.012			Kg/Kg chlorine	0.012	
NOx	Kg/Kg chlorine	0.007			Kg/Kg chlorine	0.007	
CO	Kg/Kg chlorine	0.0008			Kg/Kg chlorine	0.0008	
CO2	Kg/Kg chlorine	1.21			Kg/Kg chlorine	1.21	
H2S	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
HCl	Kg/Kg chlorine	0.00018			Kg/Kg chlorine	0.00018	
total HC's	Kg/Kg chlorine	0.006			Kg/Kg chlorine	0.006	
Heavy metals	Kg/Kg chlorine	0.000002			Kg/Kg chlorine	0.000002	

Water

	Raw/	Raw/	Raw/		Transformed	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
COD	Kg/Kg chlorine	0.00001			Kg/Kg chlorine	0.00001	
BOD	Kg/Kg chlorine	0.000003			Kg/Kg chlorine	0.000003	
Acid as H+	Kg/Kg chlorine	0.00034			Kg/Kg chlorine	0.00034	
Nitrate	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
Metal ions	Kg/Kg chlorine	0.00009			Kg/Kg chlorine	0.00009	
Cl2	Kg/Kg chlorine	0.042			Kg/Kg chlorine	0.042	
ammonia	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
dissolved organics	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
suspended particles	Kg/Kg chlorine	0.002			Kg/Kg chlorine	0.002	
Crude	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
dissolved substances	Kg/Kg chlorine	0.00005			Kg/Kg chlorine	0.00005	
HC's	Kg/Kg chlorine	0			Kg/Kg chlorine	0	
sodium	Kg/Kg chlorine	0.0028			Kg/Kg chlorine	0.0028	
Solid waste							
Production waste (not innert)	Kg/Kg chlorine	0.099			Kg/Kg chlorine	0.099	
Toxic chemicals	Kg/Kg chlorine	0.00002			Kg/Kg chlorine	0.000001	

CrO from Alaska	1000 bbl/day	1798			ton/yr	99228024	
Total					ton/yr	99228024	
Water Shipping - Lower 48	mi	0			ton-mi/yr	0	
Water Shipping - Alaska	mi	2439.6			ton-mi/yr	2.42077E+11	

Crude Oil Transport

Association of Oil Pipe Lines Data for 1990

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Pipelines	mi	0					
Water	mi	2439.6					
Highway/Motor Carrier	mi	1000					
Rail	mi	697					

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Pipelines	BTU/ton-mi	0					
Water	BTU/ton-mi	361			gal fuel/bbl CrO	0.964936049	
Highway/Motor Carrier	BTU/ton-mi	434			gal fuel/bbl CrO	0.553762025	
Rail	BTU/ton-mi	434			gal fuel/bbl CrO	0.385972132	

Water Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
SOx	lb/1000 gal fuel	27			kg/bbl CrO	0.011817566	
CO	lb/1000 gal fuel	100			kg/bbl CrO	0.043768763	
HC	lb/1000 gal fuel	50			kg/bbl CrO	0.021884382	
NOx	lb/1000 gal fuel	280			kg/bbl CrO	0.122552537	
HC - transfer	lb/1000 gal hauled	0.97			kg/bbl CrO	0.018479353	

Highway Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
HC	lb/1000 gal fuel	5.4572			kg/bbl CrO	0.001370752	
CO	lb/1000 gal fuel	15.3321			kg/bbl CrO	0.003851151	
NOx	lb/1000 gal fuel	18.6622			kg/bbl CrO	0.004687613	
HC - transfer	lb/1000 gal hauled	3.25			kg/bbl CrO	0.061915359	

Railroad Transport Emissions

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	lb/1000 gal fuel	25			kg/bbl CrO	0.00437685	
SOx	lb/1000 gal fuel	57			kg/bbl CrO	0.009979219	
CO	lb/1000 gal fuel	130			kg/bbl CrO	0.022759622	
HC	lb/1000 gal fuel	94			kg/bbl CrO	0.016456957	
NOx	lb/1000 gal fuel	370			kg/bbl CrO	0.064777386	
Aldehydes	lb/1000 gal fuel	5.5			kg/bbl CrO	0.000962907	
Organic Acids	lb/1000 gal fuel	7			kg/bbl CrO	0.001225518	
HC - transfer	lb/1000 gal hauled	3.25			kg/bbl CrO	0.061915359	

Sheet End

Sheet Title: Isopropanol (from Propene and Isobutelene. Isopropanol is used in production of TNAZ)

Sheet Description: Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing Isopropanol.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	BP deg C	Sp G	Vapor density relative to air
60.0956	Isopropanol	1.00E+00	kg	1.00E+00	kg	8.2	1.392	3.4
	Total	1.00E+00	Kg	1.00E+00	Kg			

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
Isopropanol	Kg/kg Isopropa	0.000651899		Kg/kg Isopropa	0.000651899		5
Propene	Kg/kg Isopropa	2.56305E-05		Kg/kg Isopropa	2.56305E-05		5
Water							
Na2SO4	Kg/kg Isopropa	0.016909798		Kg/kg Isopropa	0.016909798		5
Solid Wastes							
Resource Consumption							
Heat Energy (fos	MJ/Kg Isopropa	5.205045039		MJ/Kg Isopropa	5.205045039		3

Electric Power	MJ/Kg Isopropa	3.71126E-05	MJ/Kg Isopropa	3.71126E-05	3
Propene	Kg/kg Isopropa	0.989010989	Kg/kg Isopropa	0.989010989	5
sulfuric acid	Kg/kg Isopropa	0.011675824	Kg/kg Isopropa	0.011675824	4
NaOH	Kg/kg Isopropa	0.009523461	Kg/kg Isopropa	0.009523461	3

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
p.s.i.	feet water	2.03666	CRC, 66th Edition	
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG.	MJ NG	46	Calculated page C	SD=13%

d Isopropan	0.74	rel to Water	molar				kg air per kg
Mw Chlorin	70.9		dry air composition		Mwt	mass composition	component
Mw ClBz	112.56		N2	0.78084	28.0134	0.75521	1.324134
Mw Cl2Bz	147.01		O2	0.20946	31.9988	0.231406	4.321406
Mw HCl	36.4609		CO2	0.00033	44.01	0.000501	1994.319
Mw NaOH	39.9971		Ar	0.00934	39.948	0.012882	77.62792
			total	0.99997	28.96409	1	

Ideal gas density at 15 C (60 F) air (dry)

0.042296 mol/liter 42.29634021 mol/m^3 1.225075005 kg/m^3

Calculations

Isopropanol Production 1993

Source: US ITC 2810 11.94 Synthetic Organic Che Kg 576845000

US Production and Sales, 1993

Isopropanol production capacity

Source: Chem & Eng. News

Chemical Profile	Mlb	1800	
Aug 9 '93	Utilization ratio:	0.70651418	
		Capacity Mlb	Calculated production: Mlb
Exxon	Baton Rouge, LA 70821	650	459.2342169

Shell Oil Co.	Deer Park, TX 77536	600	423.9085079
Union Carbide	Texas City, TX 77590	550	388.5827989

Source: Emissions:
TRI database, 1993 data

The following reported emissions were ascribed to Isopropanol production		Isopropanol	Propene	sulfuric acid	Isopropyl ether
Exxon	Air		3.40E+05	2.00E+00	
	Water		0.00E+00		
Shell Oil Co.	Air		3.34E+05	0.00E+00	
	Water		0.00E+00		
Union Carbide	Air		1.55E+05	3.26E+04	
	Water		0.00E+00		

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg Isopropa	5.20504504			MJ/kg Isopropanol	5.205045039	
Coal	MJ/kg Isopropa	0			Kg/kg Isopropanol	0	
Oil	MJ/kg Isopropa	0			Kg/kg Isopropanol	0	
Natural Gas	MJ/kg Isopropa	0			Kg/kg Isopropanol	0	
Hydropower	MJ/kg Isopropa	0					
Fission	MJ/kg Isopropa	0					
Electricity (generic)	MJ/kg Isopropa	3.71126E-05			MJ/kg Isopropanol	3.71126E-05	

		D H evap cal/m	Mwt	D H v MJ/Kg	Kg/kg Isopropanol	MJ/Kg Propanol	
Isopropanol evaporation	from acid	10063.5	60.0956	0.700645039	1	0.700645039	
water evaporation	Acid reconstitution			2.2522	2	4.5044	
		CRC 66		Perry's 6		5.205045039	heat load

Heating load is disregarded because of the overwhelming energy requirements of evaporation and the probable recovery of that energy for other heating purposes.

Cooling
water

	25	deg C temp rise	Condensation
	0.1046	heat removal MJ/kg water	
	5.205045	MJ/kg product	heat load
c water	49.76142	Kg/Kg product	

0.7 efficiency

7.87E-05 kJ Elec/Kg — Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

		kg flow/kg propan	representative	Sp grav	Sp visc			
distillation botto	to storage	1	Isopropanol	0.7855	2.496666667	MJ/kg Isopropa	1.54392E-07	
storage	to reactor	0.25	mineral oil/whit	0.7628	2.18	MJ/kg Isopropa	3.27284E-08	25C
water dilution 2	to acid boile	12	sulfuric acid +w	2.02196	1.966466667	MJ/kg Isopropa	3.75628E-06	83 C
acid+propene a	to dilution	5	sulfuric acid +w	1.899	21.7403	MJ/kg Isopropa	1.62509E-05	25 C
clean aacid	to absorber	4	sulfuric acid +w	1.899	21.7403	MJ/kg Isopropa	1.30008E-05	25 C
water		49.76142485		1	1		3.91752E-06	
				CRC 66	CRC 66		3.71126E-05	total pumping energy per kg prod

Absorber materials at 4*weight of product stream

2	5.5	8	8	1	24.5
6	2.5			7	15.5
				40	

Co-Products:
source: See from above

Resources: Faith, Keyes and Clark'e Industrial chemicals

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.	
	Oil	Kg/kg Isopropa	0			Kg/kg Isopropanol	0		
	Natural Gas	Kg/kg Isopropa	0			Kg/kg Isopropanol	0		
	Coal	Kg/kg Isopropa	0			Kg/kg Isopropanol	0		
42.0804	Propene	Kg/.91kg Isopro	0.9		5	Kg/kg Isopropanol	0.989010989		
98.0734	sulfuric acid	Kg/.91kg Isopro	0.010625		4	Kg/kg Isopropanol	0.011675824		
	"Mineral oil"	Kg/kg Isopropa	0			Kg/kg Isopropanol	0		
39.9971	NaOH	Kg/.91kg Isopro	0.00866635		3	Kg/kg Isopropanol	0.009523461		Eng Estimate based on H2SO4 make up for treatment
	Water	Kg/kg Isopropa	0			Kg/kg Isopropanol	0		

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
SOx	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
NOx	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
Cl2	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
Isopropanol	lb/Exxon +Shel	0.00E+00		5	Kg/kg Isopropanol	0	
Propene	lb/Exxon +Shel	8.29E+05		5	Kg/kg Isopropanol	0.000651899	
sulfuric acid	lb/Exxon +Shel	3.26E+04		5	Kg/kg Isopropanol	2.56305E-05	
Isopropyl ether	lb/Exxon +Shel	0.00E+00		5	Kg/kg Isopropanol	0	
HC total	lb/Exxon +Shel	0.00E+00			Kg/kg Isopropanol	0	
Heavy meta(Cd+Ni+Cr)	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
BOD	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
Acid, H+ (Phosphoric)	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
Metal ions	lb/Exxon +Shel	0			Kg/kg Isopropanol	0	
Na2SO4 in water	lb/Exxon +Shel	0		3	Kg/kg Isopropanol	0.016909798	
Isopropanol	lb/Exxon +Shel	0.00E+00			Kg/kg Isopropanol	0	
Propene	lb/Exxon +Shel	0.00E+00			Kg/kg Isopropanol	0	
sulfuric acid	lb/Exxon +Shel	0.00E+00			Kg/kg Isopropanol	0	
Isopropyl ether	lb/Exxon +Shel	0.00E+00			Kg/kg Isopropanol	0	
Heavy metals (Cadmium, Ni	db/Exxon +Shel	0			Kg/kg Isopropanol	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert)	lb/Exxon +Glob	0			Kg/kg Isopropanol	0	
Heavy metals (Cadmium, Ni	db/Exxon +Glob	0			Kg/kg Isopropanol	0	

Offsite Transfer

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.

Sheet Title: Propylene (for polypropylene production)

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing monomer quality propylene
Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking fascilities producing monomer quality ethylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
Propylene	1.00E+00	Kg
Total	1	Kg

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
TSP	Kg/Kg propylene	0.0008					3
SOx	Kg/Kg propylene	0.004					3
NOx	Kg/Kg propylene	0.006					3
CO	Kg/Kg propylene	0.0004					3
CO2	Kg/Kg propylene	0.528					3
H2S	Kg/Kg propylene	0.00001					3
HCl	Kg/Kg propylene	0.00001					3
total HC's	Kg/Kg propylene	0.008					3
other organic	Kg/Kg propylene	0.000001					3
Heavy metals	Kg/Kg propylene	0.000001					3
Water							
COD	Kg/Kg propylene	0.0002					3
BOD	Kg/Kg propylene	0.00003					3
Acid as H+	Kg/Kg propylene	0.00004					3
Metal ions	Kg/Kg propylene	0.0002					3
Cl2	Kg/Kg propylene	0.00005					3

	Dissolved Organ	Kg/Kg propylene	0.00002		3
	suspended solid	Kg/Kg propylene	0.0002		3
	crude oil	Kg/Kg propylene	0.0001		3
	miscelanious dis	Kg/Kg propylene	0.0004		3
	Phenol	Kg/Kg propylene	0.00007		3
	Solid Wastes				
	Production waste	Kg/Kg propylene	0.009		3
Resource Consumption					
	Natural Gas	Kg/Kg propylene	0.514130435	19708333.33	3
	Coal	Kg/Kg propylene	0.000358269		
fuel	Coal	Kg/Kg propylene	0.020063053	3.569839724	3
	Hydropower	MJ/Kg propylene	0.12		
	Fission	MJ/Kg propylene	0.23		
	Iron ore	Kg/Kg propylene	0.0002		
	limestone	Kg/Kg propylene	0.0001		
	Bauxite	Kg/Kg propylene	0.0003		
	Rock salt	Kg/Kg propylene	0.006		
	Clay	Kg/Kg propylene	0.00002		
	Water	Kg/Kg propylene	1.6		

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)	BTU Coal	12000	calculation page B	SD=11%

Calculations

kg NG	MJ NG	46	Calculated page C	SD=13%

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Propylene (polymer)	1 Kg			3			
Propylene (other)							
						0	

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality propylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg propylene	0.56		3	Kg/Kg propylene	0.020063053	
Oil	MJ/Kg propylene	1.86		3	Kg/Kg propylene	0.041692407	
Natural Gas	MJ/Kg propylene	6.68		3	Kg/Kg propylene	0.145217391	
Hydropower	MJ/Kg propylene	0.12		3	MJ/Kg propylene	0.12	
Fission	MJ/Kg propylene	0.23		3	MJ/Kg propylene	0.23	

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg propylene	36.38		3	Kg/Kg propylene	0.81546762	
Natural Gas	MJ/Kg propylene	23.65		3	Kg/Kg propylene	0.514130435	
Coal	MJ/Kg propylene	0.01		3	Kg/Kg propylene	0.000358269	
Iron ore	Kg/Kg propylene	0.0002		3	Kg/Kg propylene	0.0002	
limestone	Kg/Kg propylene	0.0001		3	Kg/Kg propylene	0.0001	
Bauxite	Kg/Kg propylene	0.0003		3	Kg/Kg propylene	0.0003	
Rock salt	Kg/Kg propylene	0.006		3	Kg/Kg propylene	0.006	
Clay	Kg/Kg propylene	0.00002		3	Kg/Kg propylene	0.00002	
Water	Kg/Kg propylene	1.6		3	Kg/Kg propylene	1.6	

Output
Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg propylene	0.0008			Kg/Kg propylene	0.0008	
SOx	Kg/Kg propylene	0.004			Kg/Kg propylene	0.004	
NOx	Kg/Kg propylene	0.006			Kg/Kg propylene	0.006	

CO	Kg/Kg propylene	0.0004			Kg/Kg propylene	0.0004	
CO2	Kg/Kg propylene	0.528			Kg/Kg propylene	0.528	
H2S	Kg/Kg propylene	0.00001			Kg/Kg propylene	0.00001	
HCl	Kg/Kg propylene	0.00001			Kg/Kg propylene	0.00001	
total HC's	Kg/Kg propylene	0.008			Kg/Kg propylene	0.008	
other organic	Kg/Kg propylene	0.000001			Kg/Kg propylene	0.000001	
Heavy metals	Kg/Kg propylene	0.000001			Kg/Kg propylene	0.000001	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg propylene	0.0002			Kg/Kg propylene	0.0002	
BOD	Kg/Kg propylene	0.00003			Kg/Kg propylene	0.00003	
Acid as H+	Kg/Kg propylene	0.00004			Kg/Kg propylene	0.00004	
Metal ions	Kg/Kg propylene	0.0002			Kg/Kg propylene	0.0002	
Cl2	Kg/Kg propylene	0.00005			Kg/Kg propylene	0.00005	
Dissolved Organics	Kg/Kg propylene	0.00002			Kg/Kg propylene	0.00002	
suspended solids	Kg/Kg propylene	0.0002			Kg/Kg propylene	0.0002	
crude oil	Kg/Kg propylene	0.0001			Kg/Kg propylene	0.0001	
miscelanious dissolved mater	Kg/Kg propylene	0.0004			Kg/Kg propylene	0.0004	
Phenol	Kg/Kg propylene	0.00007			Kg/Kg propylene	0.00007	

Solid waste

Production waste (not innert)	Kg/Kg propylene	0.009			Kg/Kg propylene	0.009	

Sheet End ========= =========== =========== =========== =========== =========== ============== =========== =========== ========= ========= =========

Coal type	Moisture	Sulfur		Heat value				
	%	%	%dry	Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11121.622			
HV bit A	2.9	0.6	0.62	14170	14593.203	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352.185			
Brown Coal German - Rh	55	0.3	0.67	4830	10733.333			
Sub bit A	13.9	0.6	0.70	10330	11997.677	SD=	1295.7751	0.1081691
Meta Anthracite	9	0.7	0.77	10080	11076.923	Avg=	11979.157	
LV bit	2.9	0.8	0.82	14400	14830.072	median		
Anthracite	4.3	0.8	0.84	12880	13458.725			
Lignite	36.8	0.9	1.42	7000	11075.949			
MV bit	2.4	1.5	1.54	14490	14846.311			
Semi anthracite	2.1	1.7	1.74	13700	13993.871			
HV bit B	6.7	2.6	2.79	12390	13279.743			
HV bit C	15.4	2.9	3.43	10740	12695.035			

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

Natural gas

mol%	Mwt	heat value MJ/M^3	Rio Arriba, N	Terrell, Tex	Stanton, Kan	San Juan, NM	Olds Field, A	Cliffside, Texas	avg	SD (rel)
Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8		
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8		
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7		
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8		
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5		
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22			
H2S	34.076	23.7		0.01			35.79			
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6		
Mol wt:			16.625849	31.182	20.921258	21.28362	25.492892	20.445665	19.610242	10.79%
heating value	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7	39.766667	12.81%
	MJ/KG		50.658467	12.427683	37.366777	49.254778	26.360289	33.634514	45.760008	13.03%
	0.0224M^3/mol			too high CO2 content for use			too high Sulfur content	too low heating value(?)		

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1049.5714

Synopsis of table 9-14

mol%	Mwt	heat value MJ/M^3	Baltimore Md	Columbus Ohio	Houston Tx	Burmingham Al	Washington DC	Phoenix Az
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.37

ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11		
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26		
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13		
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0		
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61		
H2S	34.076	23.7		0.01						
N2	28.013	0	0.5	0.21	21.14	2.14	0.42	1.37	avg	SD (rel)
Mol wt:			17.126294	16.939122	23.380219	17.328208	16.9628	18.179837	18.319413	15.84%
heating value	MJ/M^3		39.2023	38.3444	38.4563	38.1952	38.8666	39.9483	38.835517	1.10%
	MJ/KG		51.273879	50.705967	36.844014	49.374551	51.324771	49.221668	48.124142	13.30%

0.0224M^3/mol

Phosphorous trichloride production from Phosphorous and chlorine.

	Mwt	DHfo		Cpo		
	kg/mol	kcal/mol	MJ/Kg	Cal/deg mo	MJ/Kg deg	
P4	123.8952	14.08	0.475488	16.05	0.54202	as gas
PCl3	137.3328	-76.4	-2.327613	17.17	0.5231	as gas
Cl2	70.906	0	0	8.104	0.4782	
water	18.0153			17.995	4.17929	
		reaction				
	137.3328	79.92	2.434854			

yield	0.95	relative to reactants
reflux ratio	0.5	

Module — Material (Kg/Kg phosphoroustrichloride) and Energy in MJ/Kg phosphoroustrichloride

Module	Phosphorous	Chlorine	Cooling water		PCl3		Fuel ?	Electricity	Energy loss	Reaction	
Reactor	0.308631	0.855984			1.1119838	-2.223968					0.0526316
	0	0			37.809375	-87.2524				2.4348537	-47.00817
	25	25			90	100					
Reflux cooler					2.2239675	-2.223968					0
					87.252403	-75.61875					11.633654
					100	90					
Condenser					1.1119838	-1.111984					0
					49.443028	-37.80937					11.633654
					100	90					
Still	-0.071223	-0.040761			1.1119838	**-1**					-1.11E-16
	-1.93019	-0.974596			37.809375	-26.15518					8.7494095
	75	75			90	75					
	0.237409	0.815223	0	0	-1	-6.559919	0	0	0	0	0.0526316

-1.93019	-0.974596	0	0	-14.52153	0	0	0	2.4348537

Cooling water

	25	deg C temp rise
	104.482135	heat removal MJ/kg water
	2.43485373	MJ/kg product
c water	0.02330402	Kg/Kg product

7.8726E-05 kJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

		representati	Sp grav	Sp visc	kgflow/kg prod		
storage	to reactor	P4	1.745	2	0.237409	1.9E-08	viscosity is a guess
reflux	to reactor	PCl3	1.575	2	1.111984	8.8E-08	viscosity is a guess
reflux	to condenser	PCl3	1.575	2	1.111984	8.8E-08	
condenser	to still	PCl3	1.575	2	1.111984	8.8E-08	
recycle	to reactor	P4	1.745	2	0.071223	5.6E-09	
cooling water			1	1	0.023304	1.8E-09	
						2.9E-07	total pumping energy per kg prod

Acetic Anhydride synthesis
Source: all process data

Technical report HDC-125-95 Pg 8
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

New heat source from NG changes coal tar, cinder and Flue gas data.
Final calculation based on producer gas required to consume the air supplied to the process.
The heat value for the producer gas is matched with standard NG, from which air requirements are taken.

Physical data are taken from:
Perry's Chemical Engineer's Handbook, Ed 6
McGraw-Hill, 1984

Kirk-Othmer Encyclopaedia of chemical technology, Ed 2, Ed 4
Wiley Interscience, 1966, 1994
Entries: Gas, Manufactured; Gas, Natural; Coal; Coal tar

			Conc.	Raw data in lb	kg per kg AcAnhd solution	kg per kg AcAnhd dry base	
Product							
		AcAnhd	0.975	2.03	1	1	
		(Water)	0.025			0.025641	
		Total		2.03	1	1.025641	
Output							
scrub	to IWTF	AcOH	0.005	0.08455	0.0416502	0.0427182	
		W	as pure	0.0841273	0.041442	0.0425046	
		AcOH	as pure	0.0004228	0.0002083	0.0002136	
mill washout to IWTF				0.2146	0.1057143	0.1084249	
		W	0.99	0.212454	0.1046571	0.1073407	
		AcOH	0.01	0.002146	0.0010571	0.0010842	
Condensate to IWTF				0.06039	0.0297488	0.0305116	
		AcOH/W	trace	0	0	0	
		Water		0.06039	0.0297488	0.0305116	
condensate to steam plant A				5.987	2.9492611	3.0248832	
cinders to block plant				0.2186	0.1076847	0.1104459	Replaced system
				0	0	0	NG system
Producer gas manufacture Coal tar to steam plant A							
		Coal tar		0.06779	0.0333941	0.0342503	
				0	0	0	NG system
Evaporator sludge from ketene gas manufacture				0.04026	0.0198325	0.020341	
	to Bldg 2	AcOH	0.9	0.036234	0.0178493	0.0183069	
		W	0.1	0.004026	0.0019833	0.0020341	
Scrubber underflow to Bldg 2				0.1208	0.0595074	0.0610332	

		AcOH		0.12	0.014496	0.0071409	0.007324		
		W		0.88	0.106304	0.0523665	0.0537092		
Refining residue to Bldg 2									
		AcOH	pure		0.3759	0.1851724	0.1899204		
Ball mill sludge to Steam Plant B					0.004828	0.0023783	0.0024393		
Inputs									
	Materials								
		AcOH		0.997	2.884	1.4206897	1.4571176		
		NH3			0.0005629	0.0002773	0.0002844		
		Eth3PO4			0.00856	0.0042167	0.0043249		
	Heat source changed	Air			0.5865	0.2889163	0.2963244		
		Coal			0.6795	0.3347291	0.3433119		Energy
	Replacement System	Air			0.4979873	0.2453139	0.251604		
		Natural Gas			0.0300438	0.0147999	0.0151794		
		EthGlycol			5.306E-05	2.614E-05	2.681E-05		
		Freon			5.383E-06	2.652E-06	2.72E-06		
		Filtered Water			13.14	6.4729064	6.6388784		
		Steam			15.03	7.4039409	7.5937855		
		River Water			1590	783.25123	803.3346		
	Energy								
		Electricity	kWhr		0.1122	0.0552709	0.0566881		
Waste									
	Water/condensate return to river (Non-contact)				1603	789.65517	809.90274		
	Steam Condensate to river (Non-contact)				8981	4424.1379	4537.5774		
Air Emiossion									
		AcOH			0.0618	0.0304433	0.0312239		
	Replaced	Flue Gas			0.9797	0.4826108	0.4949855		
	Replacement system	Flue gas			0.5280311	0.2601138	0.2667834		
		Freon			5.383E-06	2.652E-06	2.72E-06		
					lb per lb RDX base	kg per kgAcAnmix	kg per kgAcAn pure		
		Coal			0.6795	0.3347291	0.3433119		
		tar			0.06779	0.0333941	0.0342503	0.099764533 10% tar	
		Producer gas			0.4275059	0.192794	0.1331015	difference from coal and (tar+cinder)	70% gas
		Heating value	Btu		4109.6485	2024.4574	2076.3666		
		air required			0.675477	0.3327473	0.3412793		
This calculation method came up with inconsistent results		NG replacement nescf			3.9155492	1.928842	1.9782994	to equal heating values	
					0.1904544	0.0938199	0.0962255		
		Air required			3.1568477	1.5550974	1.5949717		
		Air			0.5865	0.2889163	0.2963244		
		Producer gas			0.2554196	0.1258225	0.1290487	calculated according to air supply	
		Heating value	btu		648.28993	319.35464	327.54323	calc according to heat of gas combustion	
Final calculation method		NG replacement nescf			0.6226572	0.3067277	0.3145925	heat value to equal heating values	

	0.0300438	0.0147999	0.0151794
Air required	0.4979873	0.2453139	0.251604
	1.0140059	0.4817102	0.4294258
Cinder	0.2186	0.1076847	0.1104459
Flue gas	0.9797	0.4826108	0.4949855
	1.1983	0.5902956	0.6054314

Mass balance error -15.38% is missing output, perhaps to scrubing

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1049.571429
MJ/M^3 39.14901429
MJ/Kg 50.18997432

Manufactured gas
Data from KO 2 (1964) for "modern mechanical method"

	Moisture	Heating valueBtu/lb		Gas			gas heat value				Tar data				
				Gas yield scf/ton		gas lb/lb coal	Gross heat value Btu/scf		Btu/ton coal	Btu/lb coal	Tar yield gal/ton		lb/lbcoal	energy value	
		wet	dry	wet base	dry base		wet base	dry base	wet base	wet base	wet base	dry base	wet	btu in tar/lb coal	
Anthracite	0.051	10800	11380.4	123900	130558.48		138	145.41623	17098200	8549.1	9.5	10.010537	0.0475688	810	17027.962
Belgian Coal	0.026	11980	12299.795	120900	124127.31		150	154.00411	18135000	9067.5	1	1.026694	0.0050072	83.86	16747.737
Baddesley	0.05	12080	12715.789	116100	122210.53		165.6	174.31579	19226160	9613.08	21	22.105263	0.1051521	1679.12	15968.485
															Btu/lb tar
															16.5
															Characteristic value

On the basis of 10% tar production in the process the Baddesley type coal is used
This coal then provides 9613.08 gas heating value in Btu/lb coal

Baddesley coal ga

composition	MWt	vol%	O2 per mole	mol O2 per mol gas			
CO2	44.01	6.7	0	0			
alkyls							
O2	31.9988	0	0	0			
CO	28.016	25.3	0.5	0.1265			
H2	2.0158	21	0.5	0.105			
CH4	16.043	1.8	2	0.036			
N2	28.013	45.2	0	0		0.578863788	mol air producing mol gas
Gas Mwt	23.410686			0.2675	mol O2 per mol gas	1.277093478	mol air to burn mol gas
				0.3656313	kg O2 per Kg gas	1.855957266	mol air used/mol gas
ideal gas density of producer gas				1.5800413	kgair/kg gas	2.296221153	kg air used / kg gas

1.045119911 kg/m^3
0.065244718 lb/cuf

physical data

Density of Tar	75	lb/cuf	Perry 6 (1984)
	1200	kg/m^3	
	10.01448763	lb/gal	

Units
scf is volume in cubic feet at 60 Farenheit and 30" Hg — KO 2 (1964)

density	lb/cuf	lb/gal	kg/m^3	Perry 6 (1984)
	0.062427974	0.008345406	1	
	7.480519351	1	119.8264	
	1	0.133680558	16.01846	

mass	ton (short - US)	lb	kg	Perry 6 (1984)
	1	2000		
		2.204622962	1	

Pressure	"Hg	N/m^2	atm	psia	Perry 6 (1984)
	1	3376.9	0.0333274	0.4897749	
	2.041754272	6894.8	0.0680464	1	
	30.00533033	101325	1	14.695858	
		1			
Heat value	MJ/m^3	btu/scf			Perry 6 (1984)
	0.0373	1			
Energy	MJ	Btu			Perry 6 (1984) for steam table values
	0.00105504	1			

molar dry air composition		Mwt	mass compo	kg air per kg component
N2	0.78084	28.0134	0.7552105	1.3241342
O2	0.20946	31.9988	0.2314062	4.3214062
CO2	0.00033	44.01	0.0005014	1994.3188
Ar	0.00934	39.948	0.012882	77.627923
total	0.99997	28.96409	1	

Perry 6 (1984)

Synopsis of table 9-14

mol%	Mwt	heat value MJ/M^3	Baltimore Md	Columbus Ohio	Houston Tx	Burmingham Al	Washington DC	Phoenix Az	average	molecular O2 demand per molecule	kg O2 demand per kg gas
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.37	92.616667	2	3.4185467
ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11	4.205	3.5	0.2716167
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26	1.1366667	5	0.1048879
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13	0.285	6.5	0.0341885
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0	0.0433333	8	0.0063979
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61	0.6683333		Total
H2S	34.076	23.7		0.01							3.8356377
N2	28.013	0	0.5	0.21	0.13	2.14	0.42	1.37	0.795	SD (rel)	
Mol wt:			17.126294	16.939122	17.494688	17.328208	16.9628004	18.179837	17.338492	2.26%	kg air demand
heating value	MJ/M^3		39.2023	38.3444	38.4563	38.1952	38.8666	39.9483	38.835517	1.43%	per kg gas
	MJ/KG		51.273879	50.705967	49.23901	49.374551	51.32477064	49.221668	50.189974	1.72%	16.575349
	Btu/scf		1051	1028	1031	1024	1042	1071	1041.1667		
	0.0224M^3/mol										
				288.70556	60 F						

	Carbons	Hydrogen	average oxygen demand
Methane	1	4	
ethane	2	6	
propane	3	8	
butane	4	10	
pentane+	5	12	

Acetic acid for Acetic Anhydride synthesis
Concentration of the acid
Source: for all data
Technical report HDC-125-95 Pg 6
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg Acetic acid solution	kg per kg Acetic acid dry base
Product						
				3.935	1	1.003009
		AcOH	0.997	3.923195	0.997	1
		(Water)	0.003	0.011805	0.003	0.003009
Output						
Slopwater from flashing				6.652	1.6904701	1.6955568
	to IWTF	AcOH	0.05	0.3326	0.0845235	0.0847778
		W	0.95	6.3194	1.6059466	1.610779
Low Boilers from flashing n-PropylOAc purification						
	to IWTF			0.2146	0.0545362	0.0547003
		Propylformate				
		MeOAc				
		Acetone				
		MeNO3				
		EthOAc				
Sludge from sludge heater				0.02825	0.0071792	0.0072008
	to IWTF	AcOH	0.1	0.002825	0.0007179	0.0007201
		Water	0.9	0.025425	0.0064612	0.0064807
		High b.p. materials				
condensate to steam plant A				6.264		

Inputs

Materials

	AcOH	total		3.978647	1.011092	1.0141344
Recover acid	AcOH		0.593	5.884	1.4952986	1.499798
AcAnhd recycle	AcOH		0.795	0.537	0.1364676	0.1368782
Fresh from Malinkrodt	AcOH		0.2	0.3126	0.0794409	0.07968
	Water in solution	total		2.754953	0.7001151	0.7022218
	n-PropylOAc			0.01036	0.0026328	0.0026407
	N2			0.01553	0.0039466	0.0039585
	Filtered Water			6.532	1.6599746	1.6649695
	Steam			15.66	3.9796696	3.9916446
	River Water			77.39	19.66709	19.726269
Energy						
	Electricity	kWhr		0.02044	0.0051944	0.00521
Waste						
Water return to river (Non-contact)				77.39	19.66709	19.726269
Steam Condensate to river (Non-contact)				9.395	2.3875476	2.3947318
Air Emiossion						
	AcOH			0.004242	0.001078	0.0010813
	n-PropylOAc			0.003653	0.0009283	0.0009311
	N2			0.01553	0.0039466	0.0039585

Acetic acid for Acetic Anhydride synthesis
Purification of spent acid
Source: for all data
Technical report HDC-125-95 Pg 18
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg Acetic acid solution	kg per kg Acetic acid dry base
Product						
				5.884	1	1.6666667
		AcOH	0.6	3.5304	0.6	1
		(Water)	0.4	2.3536	0.4	0.6666667
Output						
Condensate				0.09333	0.0158617	0.0264361
	to IWTF	AcOH	0.02	0.0018666	0.0003172	0.0005287
		W	0.98	0.0914634	0.0155444	0.0259074
Explosive Slurry				0.4527	0.0769375	0.1282291
	to ???	AcOH	0.372	0.1684044	0.0286207	0.0477012
		Water	0.353	0.1598031	0.0271589	0.0452649
		Salts	0.176	0.0796752	0.013541	0.0225683
		Explosive	0.099	0.0448173	0.0076168	0.0126947
ANG-77 mix				0.3733	0.0634432	0.1057387
	to ???	Nitrates of Am	0.74	0.276242	0.046948	0.0782467
		Water	0.242	0.0903386	0.0153533	0.0255888
		AcOH	0.005	0.0018665	0.0003172	0.0005287
		Explosive	0.01	0.003733	0.0006344	0.0010574
		Gum	0.003	0.0011199	0.0001903	0.0003172
Inputs						
	Materials					
	Spent Acid		total	6.073	1.032121	1.7202017
		AcOH	0.603	3.662019	0.622369	1.0372816
		HNO3 salts	0.056	0.340088	0.0577988	0.0963313
		explosives	0.008	0.048584	0.008257	0.0137616
		Water in solu	0.333	2.022309	0.3436963	0.5728272

		NH3		0.01639	0.0027855	0.0046425
		Explosive (RDX)		5.075E-05	8.625E-06	1.438E-05
		Gum		0.00112	0.0001903	0.0003172
		Filtered Water		0.02818	0.0047893	0.0079821
		Steam		4.68	0.7953773	1.3256288
		River Water		62.7	10.656016	17.760027
	Energy					
		Electricity	kWhr	0.05474	0.0093032	0.0155053
Waste						
	Water return to river (Non-contact)			62.7	10.656016	17.760027
	Steam Condensate to river (Non-contact)			3.991	0.6782801	1.1304668
Air Emiossion						
		AcOH		0.004242	0.0007209	0.0012016
		n-PropylOAc		0.003653	0.0006208	0.0010347
		N2		0.01553	0.0026394	0.0043989

Acetic acid treatment and Acetic Anhydride synthesis
Area A Steam Plant
Source: for all data
Technical report HDC-125-95 Pg 24
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg Steam	kg per kg Steam	
Product							
		Steam		31.07	1	1	
						0.8858407	weighted according to coal utilization
Output							
To Block Plant		Cinders		0.2619	0.0084294	0.0074671	
		Fly Ash		0.04937	0.001589	0.0014076	
to IWTF		Boiler blowdown		0.777	0.025008	0.0221531	
	with:	Phosphates					
		Sulfates					
		Sulfites					
		Cooling Water		5.413	0.1742195	0.1543307	
	with:	fly ash					
		cinders					
Inputs							
	Materials						
1992	Old numbers	Coal		3.182	0.1024139	0.0907224	
		Coal Tar		0.06779	0.0021818	0.0019328	Eliminated due to replacement of Coal producer gas by NG
1995	Updated	Coal		3.2313018	0.1040007	0.0921281	Sufficient coal to replace Coal tar heating value
		Air		44.55	1.433859	1.2701707	Assumed to remain the same due to similar H and C balance in Coal and tar
		Boiler water		19.42	0.6250402	0.5536861	
		Condensate		12.43	0.4000644	0.3543933	
		Filtered Water		1.624	0.0522691	0.0463021	
		River Water		3.789	0.1219504	0.1080287	
		Disodium Phosphate		4.922E-05	1.584E-06	1.403E-06	
		Sodium Sulfite		2.538E-05	8.169E-07	7.236E-07	
	Energy						
		Electricity	kWhr	0.04629	0.0014899	0.0013198	
Waste							
		Fly Ash to Landfill		0.2045	0.0065819	0.0058305	
Air Emiossion							
		VOCs		7.921E-05	2.549E-06	2.258E-06	
		NOx		0.02179	0.0007013	0.0006213	
		CO		0.007954	0.000256	0.0002268	

SOx	0.06045	0.0019456	0.0017235
Particulates	0.0007636	2.458E-05	2.177E-05
Flue gas	47.19	1.5188285	1.3454401

Data from KO 2 (1964) for "modern mechanical method"

	Moisture	Heating valueBtu/lb		Gas			gas heat value				Tar data				
				Gas yield scf/ton		gas lb/lb coa	Gross heat value Btu/scf		Btu/ton coal	Btu/lb coal	Tar yield gal/ton		lb/lbcoal	energy value	
		wet	dry	wet base	dry base		wet base	dry base	wet base	wet base	wet base	dry base	wet	btu in tar/lb coal	
Anthracite	0.051	10800	11380.4	123900	130558.48		138	145.41623	17098200	8549.1	9.5	10.010537	0.0475688	810	17027.962
Belgian Coa	0.026	11980	12299.795	120900	124127.31		150	154.00411	18135000	9067.5	1	1.026694	0.0050072	83.86	16747.737
Baddesley	0.05	12080	12715.789	116100	122210.53		165.6	174.31579	19226160	9613.08	21	22.105263	0.1051521	1679.12	15968.485
															Btu/lb tar
															16500
															Characteristic value

Wet Coal heating value
taken as 12000 Btu/lb

Kentucky - Tenn - Ohio Coals
typically 14000 Btu/lb ASTM "Moist"

Coal utilization breakdown for by product distribution

		lb/lb RDX	
Coal	Coal	3.182	
	Cinders	0.2619	
	Ash	0.25387	
	Energy coal	2.66623	88.58%
	Cinder Coal	0.3436	11.42%
	Utilized coal	3.00983	100.00%

Acetic acid treatment and Acetic Anhydride synthesis
Area A Water filtration
Source: for all data
Technical report HDC-125-95 Pg 28
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

		Conc.	Raw data in lb	kg per kg Filtered wate	kg per kg Boiler water	kg per kg Filtered wate	kg per kg Boiler water	
Product								
		Filtered water	130.8	1	6.7353244	1	0.8707229	
		Boiler Water	19.42	0.1484709	1	0.1292771	1	
			150.22			0.8707229	0.1292771	
Output								
to IWTF		Water	0.6891	0.0052683	0.035484	0.0045873	0.0006811	0.0052683
	with:	Alum	0.02785	0.0002129	0.0014341	0.0001854	2.753E-05	
		Ion exchange regeneration	1.426	0.0109021	0.0734295	0.0094927	0.0014094	
	with:	H2SO4						
		CaSO4						
		MgSO4						
		NaCl						
		CaCl2						
		MgCl2						
Inputs								
	Materials							
		River water	304	2.324159	15.653965	2.0236986	0.3004604	

	Hydrated lime		7.229E-05	5.527E-07	3.722E-06	4.812E-07	7.145E-08
	Al Sulfate		0.002363	1.807E-05	0.0001217	1.573E-05	2.335E-06
	Cl2		3.999E-05	3.057E-07	2.059E-06	2.662E-07	3.952E-08
	H2SO4		0.003582	2.739E-05	0.0001844	2.385E-05	3.54E-06
	Rock Salt		0.002891	2.21E-05	0.0001489	1.925E-05	2.857E-06
Energy							
	Electricity	kWhr	0.1569	0.0011995	0.0080793	0.0010445	0.0001551
Waste							
Air Emiossion							

Industrial Wastewater Treatment Facility
Both areas
Source: for all data
Technical report HDC-125-95 Pg 32
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

			Conc.	Raw data in lb	kg per kg wastewater	
Product						
Output						
Inputs						
	Materials					
IWTF streams		Wastewater		329.5	1	
		NaOH 20%		0.0314	9.53E-05	
		NaOH	0.2	0.00628	1.906E-05	
		water	0.8	0.02512	7.624E-05	
		Quicklime		0.002363	7.171E-06	
		FeCl2 25-35%		0.01109	3.366E-05	
		FeCl2	0.3	0.003327	1.01E-05	
		water	0.7	0.007763	2.356E-05	
		HCl 33%		0.0002453	7.445E-07	
		HCl	0.33	8.095E-05	2.457E-07	
		water	0.67	0.0001644	4.988E-07	
		Magnifloc 496		3.691E-05	1.12E-07	flocculant
		Filtered water		14.96	0.0454021	
	Energy					
		Electricity	kWhr	0.2042	0.0006197	
Waste						
		Treated Industrial waste water		344.3	1.0449165	
	landfill	Biological sludge		0.1533	0.0004653	
	landfill	Alum Sludge		0.1154	0.0003502	

Sheet Title: Acetic Acid (for input at 20% concentration into Holston facility)

Sheet Description: Engineering calculation (rough)
This page calculates the vendor emissions from a plant producing Acetic acid.
Not included are raw material production or extraction or water and energy use.
(Energy balance is assumed to be close to 0 due to exothermic producer gas synthesis process)

References/Citations: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed, 1991-4
Wiley Interscience,

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
Acetic acid	1.00E+00	kg
Coal Tar	1.05E-01	Kg
Total	1.10515212	Kg

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
TSP	Kg/Kg Acetic a	0.0085		Kg/Kg Acetic a	0.007691249		3
SOx	Kg/Kg Acetic a	0.01865878		Kg/Kg Acetic a	0.016883452		3
CO	Kg/Kg Acetic a	0.04618681		Kg/Kg Acetic a	0.041792268		3
CO2	Kg/Kg Acetic a	0.11356324		Kg/Kg Acetic a	0.102758018		3
total HC's	Kg/Kg Acetic a	0.03426683		Kg/Kg Acetic a	0.031006436		3
Water							

Production waste	Kg/Kg Acetic a	0.03599021		

Resource Consumption

Coal	Kg/Kg Acetic a	0.47330006	Kg/Kg Acetic a	0.428266893
Methanol	Kg/Kg Acetic a	0.5367573	Kg/Kg Acetic a	0.485686352

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Calculations

Acetic acid Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/kg ethylene	0		3	kg/kg ethylene	0	
Oil	MJ/kg ethylene	0	15	3	kg/kg ethylene	0	0.33622909
Natural Gas	MJ/kg ethylene	0		3	kg/kg ethylene	0	
Hydropower	MJ/kg ethylene	0		3			

	Fission	MJ/kg ethylene	0		3

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Methanol Carbonylation method

Stoichiometric ratios:

Methanol net	Kg/Kg Acetic a	0.533		
CO net	Kg/Kg Acetic a	0.467		
Methanol input	Kg/Kg Acetic a	0.5367573	0.993	0.993 conversion of methanol
CO input	Kg/Kg Acetic a	0.51318681	0.91	0.91 conversion of CO
Producer-Gas input	Kg/Kg Acetic a	1.69497376		from Faith Keyes and Clark's Industrial chemicals, 1975
Coal input	Kg/Kg Acetic a	0.47330006		

Emission calculation (Data from pg D and from AP42 Ed 4 Tbl 1.1-1)

Air				
CO released from process	Kg/Kg Acetic a	0.04618681	0.09	unconverted CO
Methane	Kg/Kg Acetic a	0.03050953		
CO2	Kg/Kg Acetic a	0.11356324		
Particulates	Kg/Kg Acetic a	0.0085	8.5	g/kg in Cyclone trap outlet (AP42 Ed 4 tbl 1.1-1)
Methanol	Kg/Kg Acetic a	0.0037573	0.007	unconverted assumed to escape in vent stream
SOx	Kg/Kg Acetic a	0.01865878	19.5*%S in Co	from AP 42 Ed 4 (1985) tbl 1.1-1
				Coal assumed to have 1% Sulfur and the coal tar product to have 0.4% sulfur
Land				
Ash	Kg/Kg Acetic a	0.03599021	0.094	Ash in coal (assumed recovered) but for air emission

CO production from Coal through synthesis gas (producer or manufactured)

Source: Page D calculations

Producer gas from Coal (Baddelsey)

25.30% mol CO 30.28% wt CO

Mw CO 28.016
Mw Produc 23.410686

Gas product yield from coal: 3.58118218 lb gas/lb coal

Co-Products:

source: calculated from data on this sheet and on sheet D
Coal tar heating value is median for data of Perry Ed 6 (1984) tbl. 9-12

Coal Tar	Kg/Kg Acetic a	0.10515212

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil					Kg/Kg Acetic acid		
Natural Gas					Kg/Kg Acetic acid		
Coal	Kg/Kg Acetic a	0.47330006		3	Kg/Kg Acetic acid	0.47330006	
Iron ore	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Methanol	Kg/Kg Acetic a	0.5367573		3	Kg/Kg Acetic acid	0.5367573	
Bauxite	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Rock salt	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Clay	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Output

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
TSP	Kg/Kg Acetic a	0.0085			Kg/Kg Acetic acid	0.0085	
SOx	Kg/Kg Acetic a	0.01865878			Kg/Kg Acetic acid	0.01865878	
NOx	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
CO	Kg/Kg Acetic a	0.04618681			Kg/Kg Acetic acid	0.04618681	
CO2	Kg/Kg Acetic a	0.11356324			Kg/Kg Acetic acid	0.11356324	
H2S	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
HCl	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
total HC's	Kg/Kg Acetic a	0.03426683			Kg/Kg Acetic acid	0.03426683	
other organic	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Heavy metals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
BOD	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Acid as H+	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Metal ions	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Cl2	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Dissolved Organics	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

suspended solids	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
crude oil	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
miscelanious dissolved mate	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	
Phenol	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0	

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert	Kg/Kg Acetic a	0.03599021			Kg/Kg Acetic acid	0.00128	
Toxic chemicals	Kg/Kg Acetic a	0			Kg/Kg Acetic acid	0.000001	

Sheet Title: MEK (from sec-butanol which is from n-butene which is a byproduct of butadiene production from ethylene. MEK is used in production of TNAZ)

Sheet Description:
Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing PCl3.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units
137.329	PCl3	1.00E+00	kg	1.00E+00	kg
	Total	1.00E+00	Kg	1.00E+00	Kg

Notes:

LCI components		Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air								
	Cl2	Kg/kg MEK	4.18147E-06		Kg/kg MEK	4.18147E-06		3
	Zinc oxides/Phos	Kg/kg MEK	1.136721242		Kg/kg MEK	1.136721242		3
Water								
	Dissolved Organ	Kg/kg MEK	1.73292E-05		Kg/kg MEK	1.73292E-05		3
Solid Wastes								
in container	P4 production w	Kg/kg MEK	5.85013E-07		Kg/kg MEK	5.85013E-07		
	Zinc Compounds	Kg/kg MEK	3.80251E-05		Kg/kg MEK	3.80251E-05		

Resource Consumption

Chlorine	Kg/kg MEK	1.73292E-05	Kg/kg MEK	1.73292E-05

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Mw Benzen	78.1134
Mw Chlorin	70.9
Mw ClBz	112.56
Mw Cl2Bz	147.01
Mw HCl	36.4609
Mw NaOH	39.9971

molar dry air composition		Mwt	mass composition	kg air per kg component
N2	0.78084	28.0134	0.75521	1.324134
O2	0.20946	31.9988	0.231406	4.321406
CO2	0.00033	44.01	0.000501	1994.319
Ar	0.00934	39.948	0.012882	77.62792
total	0.99997	28.96409	1	

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter 42.29634021 mol/m^3 1.225075005 kg/m^3

Calculations

MEK Production 1993

Source: US Chemical Industry Statistical Handbook 1994
Chemical Manufacturers Association, Washington DC

m ton 244500 Mlb 539.0247

MEK production capacity

Source: SRI 1991 Directory of Chemical Producers, US

Mlb 540

Utilization ratio: Full 0.998193889

Shell Corporation production Mlb 230
at Norco, LA 70079
Calculated production: 229.5845944

Source: Emissions:
TRI database, 1993 data

The Norco Plant of Shell produces ethylene and propylene and some butylene from mixed LPG (ethane and propane) feedstocks and then manufactures derivatives of butenes into MEK
Production data includes captive production and therefore all relevant emissions may be attributed to that quantity.

The following reported emissions were deemed unrelated to MEK producti	Allyl Cl	diethanolamine	1,3 dichloropropylene		4 4' iso propyledene diphe	epichlorhydchlorobenz HCl	Cl2	1,2 dichloropropane
The following reported emissions were ascribed to MEK production only:	MEK	Methyl iso butyl ke	sec-butyl alcohol	Acetone				
Emissions allocated between the products (cracker by products)	styrene	toluene	propylene	xylene	ammonia	sulfuric acid titanium tetrachloride	naphthalene	

Energy and materail input data from the calculations of sheet "Calc"

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg PCl3	0			MJ/kg PCl3	0	
Coal	MJ/kg PCl3	0			Kg/kg MEK	0	
Oil	MJ/kg PCl3	0	15		Kg/kg MEK	0	
Natural Gas	MJ/kg PCl3	0			Kg/kg MEK	0	
Hydropower	MJ/kg PCl3	0					
Fission	MJ/kg PCl3	0					
Electricity (generic)	MJ/kg PCl3	2.88758E-07			MJ/kg P4	2.88758E-07	
						Probably different mix in US	

Material input

Co-Products:
source: See from above

Resources:

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.	
Oil	Kg/kg MEK	0		4	Kg/kg MEK	0		
Natural Gas	Kg/kg MEK	0		4	Kg/kg MEK	0		
Coal	Kg/kg MEK	0		4	Kg/kg MEK	0		
Naphtha	lb/Shell, Norco	431616341		4	Kg/kg MEK	1.879988255		
ammonia	Kg/kg MEK	1.73292E-05		4	Kg/kg MEK	1.73292E-05		(all out into water emission)
Silicate (sand)	Kg/kg MEK	0		4	Kg/kg MEK	0		
Air	Kg/kg MEK	0		4	Kg/kg MEK	0		
Water	Kg/kg MEK	0		4	Kg/kg MEK	0		

Air

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
styrene	TSP	Kg/kg MEK	0			Kg/kg MEK	0	
	SOx	lb/Shell, Norco	0			Kg/kg MEK	0	
	NOx	lb/Shell, Norco	0			Kg/kg MEK	0	
	Cl2	lb/Shell, Norco	960			Kg/kg MEK	4.18147E-06	
	CO2	Kg/kg MEK	0		3	Kg/kg MEK	0	
	P4	lb/Shell, Norco	0			Kg/kg MEK	0	
	Styrene	lb/Shell, Norco	1.136721242			Kg/kg MEK	4.95121E-09	
	toluene	lb/Shell, Norco	878.375505			Kg/kg MEK	3.82593E-06	
	propylene	lb/Shell, Norco	2898.639166			Kg/kg MEK	1.26256E-05	
	xylene	lb/Shell, Norco	129.9479056			Kg/kg MEK	5.66013E-07	
	ammonia	lb/Shell, Norco	7.233680629			Kg/kg MEK	3.15077E-08	
	sulfuric acid	lb/Shell, Norco	126.8994259			Kg/kg MEK	5.52735E-07	
	titanium tetrachloride	lb/Shell, Norco	191.2791835			Kg/kg MEK	8.33153E-07	
	naphthalene	lb/Shell, Norco	82.67063576			Kg/kg MEK	3.60088E-07	
	MEK	lb/Shell, Norco	68000			Kg/kg MEK	0.000296187	
	Methyl iso butyl ketone	lb/Shell, Norco	15			Kg/kg MEK	6.53354E-08	

	sec-butyl alcohol	lb/Shell, Norco	81000			Kg/kg MEK	0.000352811	
	Acetone	lb/Shell, Norco	850			Kg/kg MEK	3.70234E-06	
	HC total	lb/Shell, Norco	154181.1822			Kg/kg MEK	0.000671566	
	Heavy meta(Cd+Ni+Cr)	lb/Shell, Norco	0			Kg/kg MEK	0	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	lb/Shell, Norco	0		5	Kg/kg MEK	0	
BOD	lb/Shell, Norco	0		5	Kg/kg MEK	0	
Acid, H+ (Phosphoric)	lb/Shell, Norco	0		5	Kg/kg MEK	0	
Metal ions	lb/Shell, Norco	0		5	Kg/kg MEK	0	
Cl2	lb/Shell, Norco	0		5	Kg/kg MEK	0	
Ammonia	lb/Shell, Norco	3978.524346		5	Kg/kg MEK	1.73292E-05	
suspended solids	lb/Shell, Norco	0		5	Kg/kg MEK	0	
crude oil	lb/Shell, Norco	0		5	Kg/kg MEK	0	
miscelanious dissolved mate	lb/Shell, Norco	0		5	Kg/kg MEK	0	
Phenol	lb/Shell, Norco	0		5	Kg/kg MEK	0	

Solid waste

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Production waste (not innert)	lb/Shell, Norco	134.3100149		5	Kg/kg MEK	5.85013E-07	
Shipped out	total no catalyst	lb/Shell, Norco	8729.971082		5	Kg/kg MEK	3.80251E-05	
	styrene	lb/Shell, Norco	8.78375505		6	Kg/kg MEK	3.82593E-08	
	toluene	lb/Shell, Norco	51.66914735		7	Kg/kg MEK	2.25055E-07	
	xylene	lb/Shell, Norco	5.683606209		8	Kg/kg MEK	2.4756E-08	
	sulfuric acid	lb/Shell, Norco	25.83457368		9	Kg/kg MEK	1.12527E-07	
	titanium tetrachloride	*lb/Shell, Norco*	*14054.00808*		*10*	*Kg/kg MEK*	*6.12149E-05*	
	MEK	lb/Shell, Norco	3000		11	Kg/kg MEK	1.30671E-05	
	Methyl iso butyl ketone	lb/Shell, Norco	30		12	Kg/kg MEK	1.30671E-07	
	Acetone	lb/Shell, Norco	5608		13	Kg/kg MEK	2.44267E-05	
	Heavy metals (Cadmium, Ni	db/Shell, Norco	0		5	Kg/kg MEK	0	

Sheet End ======== ============ =========== =========== =========== =========== ============= ============= =========== =================== ========= ========

Values are in capacity Mlb/yr 1993

Source: SRI Directory of Chemical Producers, US
1993, edition
SRI International, Menlo Park, CA

1400	0.297682	Propylene										
	C3H6											
	42.081											
						E/P ratio						
2560	0.544333	**ethylene**	cracked with steam			**1.8285714**		26.31	2.5925926	**1.937888**		
	C2H4		(hydrocracking)					Ethane	Propane	**Naphtha**		
	28.054											
				E		31.2	2560					
500	0.106315	Butadiene		P		16.1	1400					
	C4H6			BD		4.5	500					
	54.092			B		4.5	243					
						56.3	4703	8353.5	431.61634			
243	0.051669	**n Butene**	partial oxida	270	0.841099	**sec butanol**	dehydrogenation over catalyst	230	0.8757179	**MEK**	0.038058	of ethylene emissions
	C4H8					C4H10O				C4H8O		
	56.108					74.12				72.1		
											0.875718	of sec butanol emissions
4703												

100% weighted	Air	Water	land	waste shipped out
MEK	68000		130	3000
Methyl iso butyl ketone	15			30
sec-butyl alcohol	81000		4	
Acetone	850			5608

Cracker weighted	0.0516691							
	Air	Water	land	waste shipped out	Air	Water	land	waste shipped out
styrene	22			170	1.136721			8.783755
toluene	17000			1000	878.3755			51.66915
propylene	56100				2898.639			

xylene	2515			110		129.9479			5.683606
ammonia	140	77000				7.233681	3978.5		
sulfuric acid	2456		6	500		126.8994		0.3100149	25.83457
titanium tetrachloride	3702			272000	reclamation	191.2792			14054.01
naphthalene	1600					82.67064			

Sheet Title: butylene (for butadiene and rubber production)

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing monomer quality butylene
Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking fascilities producing monomer quality ethylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Summary Output

Co-product Allocation Calculations

Co-product	Quantity	Units
butylene	1.00E+00	Kg
Total	1	Kg

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
TSP	Kg/Kg butylene	0.0008					3
SOx	Kg/Kg butylene	0.004					3
NOx	Kg/Kg butylene	0.006					3
CO	Kg/Kg butylene	0.0004					3
CO_2	Kg/Kg butylene	0.5					3
H_2S	Kg/Kg butylene	0.000001					3
HCl	Kg/Kg butylene	0.00001					3
total HC's	Kg/Kg butylene	0.007					3
other organic	Kg/Kg butylene	0.000001					3
Heavy metals	Kg/Kg butylene	0.000001					3
Water							
COD	Kg/Kg butylene	0.0002					3
BOD	Kg/Kg butylene	0.00004					3
Acid as H^+	Kg/Kg butylene	0.00004					3
Metal ions	Kg/Kg butylene	0.0003					3
Cl_2	Kg/Kg butylene	0.00005					3

	Dissolved Organ	Kg/Kg butylene	0.00002			3
	suspended solid	Kg/Kg butylene	0.0002			3
	crude oil	Kg/Kg butylene	0.0001			3
	miscelanious dis	Kg/Kg butylene	0.0004			3
	total HC's	Kg/Kg butylene	0.00009			
	Phenol	Kg/Kg butylene	0.000001			3
	Solid Wastes					
	Production waste	Kg/Kg butylene	0.0083			3
Resource Consumption						
	Natural Gas	Kg/Kg butylene	0.533478261	20450000		3
fuel	Natural Gas	Kg/Kg butylene	0.143913043	5516666.667	#VALUE!	
	Crude Oil	Kg/Kg butylene	0.789017599	140.3907175	#VALUE!	
fuel	Crude Oil	Kg/Kg butylene	0.036088589	6.421279978	#VALUE!	
	Coal	Kg/Kg butylene	0.000358269			
fuel	Coal	Kg/Kg butylene	0.017196902	3.059862621		3
	Hydropower	MJ/Kg butylene	0.06			
	Fission	MJ/Kg butylene	0.22			
	Iron ore	Kg/Kg butylene	0.0002			
	limestone	Kg/Kg butylene	0.0001			
	Bauxite	Kg/Kg butylene	0.0003			
	Rock salt	Kg/Kg butylene	0.006			
	Clay	Kg/Kg butylene	0.00002			
	Water	Kg/Kg butylene	1.6			

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference
BTU	J	1055.056	CRC, 66th Edition
Wh	J	3600	CRC, 66th Edition
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%
gal	L	3.785412	CRC, 66th Edition
kg	lb	2.2046226	CRC, 66th Edition
yr	day	365	
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition
gal CrO	lb CrO	7.2	

ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry)	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Calculations

Ethylene Production

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
butylene (polymer)	1 Kg			3			
butylene (other)							
						0	

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality butylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Coal	MJ/Kg butylene	0.48		3	Kg/Kg butylene	0.017196902	
Oil	MJ/Kg butylene	1.61		3	Kg/Kg butylene	0.036088589	
Natural Gas	MJ/Kg butylene	6.62		3	Kg/Kg butylene	0.143913043	
Hydropower	MJ/Kg butylene	0.06		3	MJ/Kg butylene	0.06	
Fission	MJ/Kg butylene	0.22		3	MJ/Kg butylene	0.22	

Probably different mix in US

Material input

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Oil	MJ/Kg butylene	35.2		3	Kg/Kg butylene	0.789017599	
Natural Gas	MJ/Kg butylene	24.54		3	Kg/Kg butylene	0.533478261	
Coal	MJ/Kg butylene	0.01		3	Kg/Kg butylene	0.000358269	
Iron ore	Kg/Kg butylene	0.0002		3	Kg/Kg butylene	0.0002	
limestone	Kg/Kg butylene	0.0001		3	Kg/Kg butylene	0.0001	
Bauxite	Kg/Kg butylene	0.0003		3	Kg/Kg butylene	0.0003	
Rock salt	Kg/Kg butylene	0.006		3	Kg/Kg butylene	0.006	
Clay	Kg/Kg butylene	0.00002		3	Kg/Kg butylene	0.00002	
Water	Kg/Kg butylene	1.6		3	Kg/Kg butylene	1.6	

Output
Air

	Raw/	Raw/	Raw/		Transformed	Transformed	Transformed

LCI component	Input Units	Input Quan.	Input Std. Dev.	DQI	Units	Quan.	Std. Dev.
TSP	Kg/Kg butylene	0.0008			Kg/Kg butylene	0.0008	
SOx	Kg/Kg butylene	0.004			Kg/Kg butylene	0.004	
NOx	Kg/Kg butylene	0.006			Kg/Kg butylene	0.006	
CO	Kg/Kg butylene	0.0004			Kg/Kg butylene	0.0004	
CO2	Kg/Kg butylene	0.5			Kg/Kg butylene	0.5	
H2S	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
HCl	Kg/Kg butylene	0.00001			Kg/Kg butylene	0.00001	
total HC's	Kg/Kg butylene	0.007			Kg/Kg butylene	0.007	
other organic	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
Heavy metals	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
COD	Kg/Kg butylene	0.0002			Kg/Kg butylene	0.0002	
BOD	Kg/Kg butylene	0.00004			Kg/Kg butylene	0.00004	
Acid as H+	Kg/Kg butylene	0.00004			Kg/Kg butylene	0.00004	
Metal ions	Kg/Kg butylene	0.0003			Kg/Kg butylene	0.0003	
Cl2	Kg/Kg butylene	0.00005			Kg/Kg butylene	0.00005	
Dissolved Organics	Kg/Kg butylene	0.00002			Kg/Kg butylene	0.00002	
suspended solids	Kg/Kg butylene	0.0002			Kg/Kg butylene	0.0002	
crude oil	Kg/Kg butylene	0.0001			Kg/Kg butylene	0.0001	
miscelanious dissolved mater	Kg/Kg butylene	0.0004			Kg/Kg butylene	0.0004	
HC's	Kg/Kg butylene	0.00009			Kg/Kg butylene	0.00009	
Phenol	Kg/Kg butylene	0.000001			Kg/Kg butylene	0.000001	
Solid waste							
Production waste (not innert)	Kg/Kg butylene	0.0083			Kg/Kg butylene	0.0083	

Sheet End

Coal type	Moisture %	Sulfur %	%dry	Heat value Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11121.622			
HV bit A	2.9	0.6	0.62	14170	14593.203	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352.185			
Brown Coal German - Rh	55	0.3	0.67	4830	10733.333			
Sub bit A	13.9	0.6	0.70	10330	11997.677	SD=	1295.7751	0.1081691
Meta Anthracite	9	0.7	0.77	10080	11076.923	Avg=	11979.157	
LV bit	2.9	0.8	0.82	14400	14830.072	median		
Anthracite	4.3	0.8	0.84	12880	13458.725			
Lignite	36.8	0.9	1.42	7000	11075.949			
MV bit	2.4	1.5	1.54	14490	14846.311			
Semi anthracite	2.1	1.7	1.74	13700	13993.871			
HV bit B	6.7	2.6	2.79	12390	13279.743			
HV bit C	15.4	2.9	3.43	10740	12695.035			

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

Natural gas

mol%	Mwt	heat value MJ/M^3	Rio Arriba, N	Terrell, Tex	Stanton, Kan	San Juan, NM	Olds Field, A	Cliffside, Texas	avg	SD (rel)
Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8		
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8		
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7		
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8		
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5		
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22			
H2S	34.076	23.7		0.01			35.79			
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6		
Mol wt:			16.625849	31.182	20.921258	21.28362	25.492892	20.445665	19.610242	10.79%
heating value	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7	39.766667	12.81%
	MJ/KG		50.658467	12.427683	37.366777	49.254778	26.360289	33.634514	45.760008	13.03%
	0.0224M^3/mol			too high CO2 content for use			too high Sulfur content	too low heating value(?)		

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1049.5714

Synopsis of table 9-14

mol%	Mwt	heat value MJ/M^3	Baltimore Md	Columbus Ohio	Houston Tx	Burmingham Al	Washington DC	Phoenix Az
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.37

ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11			
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26			
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13			
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0			
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61			
H2S	34.076	23.7		0.01							
N2	28.013	0	0.5	0.21	21.14	2.14	0.42	1.37			
Mol wt:			17.126294	16.939122	23.380219	17.328208	16.9628	18.179837		avg	SD (rel)
heating value	MJ/M^3		39.2023	38.3444	38.4563	38.1952	38.8666	39.9483		18.319413	15.84%
	MJ/KG		51.273879	50.705967	36.844014	49.374551	51.324771	49.221668		38.835517	1.10%
										48.124142	13.30%

0.0224M^3/mol

Sheet Title: MTBE (from Methanol and Isobutelene. MTBE is used in production of TNAZ)

Sheet Description:
Emissions are from TRI database.
Engineering calculation of the Energy requirements.
Precursor material requirements are from EIA.
This page calculates the vendor emissions from a plant producing MTBE.
Not included are raw material production or extraction or water use.

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US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	BP deg C	Sp G	Vapor density relative to air
88.1492	MTBE	1.00E+00	kg	1.00E+00	kg	8.2	1.392	3.4
	Total	1.00E+00	Kg	1.00E+00	Kg			

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity	Std. Dev.	DQI
Air							
MTBE	Kg/kg MTBE	7.31922E-06		Kg/kg MTBE	7.31922E-06		5
Methanol	Kg/kg MTBE	2.13838E-05		Kg/kg MTBE	2.13838E-05		5
Ammonia	Kg/kg MTBE	4.09116E-09		Kg/kg MTBE	4.09116E-09		5
Water							
MTBE	Kg/kg MTBE	3.25744E-08		Kg/kg MTBE	3.25744E-08		5
Methanol	Kg/kg MTBE	5.42907E-06		Kg/kg MTBE	5.42907E-06		5
Ammonia	Kg/kg MTBE	1.65873E-07		Kg/kg MTBE	1.65873E-07		5
Solid Wastes							

Resource Consumption

Electric Power	MJ/Kg MTBE	9.94219E-08	MJ/Kg MTBE	9.94219E-08	3
Isobutylene	Kg/kg MTBE	0.844445946	Kg/kg MTBE	0.844445946	5
Methanol	Kg/kg MTBE	0.273010811	Kg/kg MTBE	0.273010811	5

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5%	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
p.s.i.	feet water	2.03666	CRC, 66th Edition	
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

d MTBE	0.74	rel to Water	molar				kg air per kg
Mw Chlorin	70.9		dry air composition		Mwt	mass composition	component
Mw ClBz	112.56		N2	0.78084	28.0134	0.75521	1.324134
Mw Cl2Bz	147.01		O2	0.20946	31.9988	0.231406	4.321406
Mw HCl	36.4609		CO2	0.00033	44.01	0.000501	1994.319
Mw NaOH	39.9971		Ar	0.00934	39.948	0.012882	77.62792
			total	0.99997	28.96409	1	

Ideal gas density at 15 C (60 F)

				air (dry)	
0.042296	mol/liter	42.29634021	mol/m^3	1.225075005	kg/m^3

Calculations

MTBE Production

Source: US ITC 2810 11.94 Synthetic Organic Che Kg — 1993: 5547491608 — 5547491608

US Production and Sales, 1993

MTBE production capacity

Source: SRI 1993 Directory of Chemical Producers, US

Mlb 15149

Utilization ratio: chemical industry average 199 0.80732229

		Capacity Mlb	Calculated production: Mlb
Global Octanes Corporation	Deer Park, Tx	1150	928.4206337

Exxon | Baton Rouge, LA 70821 | 333 | 268.8383226

Source: Emissions:
TRI database, 1993 data
The Van de Mark plant is the only manufacturer of MTBE for open sale on the market so only its TRI data are used

The following reported emissions were ascribed to MTBE production only:		MTBE	Methanol	Isobutylene	Cr	Ammonia
Global Octanes Corporation	Air	3.00E+00	2.00E+00			4
	Water	0.00E+00	0.00E+00			154
Exxon	Air	8.76E+03	2.56E+04			
	Water	3.90E+01	6.50E+03			

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Fossil fuel (general)	MJ/kg MTBE	0			MJ/kg MTBE	0	
Coal	MJ/kg MTBE	0			Kg/kg MTBE	0	
Oil	MJ/kg MTBE	0			Kg/kg MTBE	0	
Natural Gas	MJ/kg MTBE	0			Kg/kg MTBE	0	
Hydropower	MJ/kg MTBE	0					
Fission	MJ/kg MTBE	0					
Electricity (generic)	MJ/kg MTBE	9.94219E-08			MJ/kg MTBE	9.94219E-08	

Cooling
water
25 deg C temp rise
0 heat removal MJ/kg water
0 MJ/kg product
c water 0 Kg/Kg product

0.7 efficiency

7.87E-05 kJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

		representative m	Sp grav	Sp visc	kgflow/kg prod									
reactor	to wash, to	MTBE	0.74	0.233	MJ/kg MTBE	1.35739E-08	vicosity of EE ether	200 psi =	376.7821					
storage	to reactor	Methanol to P=20	0.791	0.597	MJ/kg MTBE	7.87077E-08								
storage	to reactor	Isobutylene P to	0.5942	0.223	MJ/kg MTBE	7.14023E-09			2	5.5	8	8	1	24.5
cooling water			1	1	0	0			6	2.5			7	15.5
		CRC 66	CRC 66			9.94219E-08	total pumping energy per kg prod							
		MTBE from Hawley's												

40

Co-Products:
source: See from above

Resources: Faith, Keyes and Clark'e Industrial chemicals

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
	Oil	Kg/kg MTBE	0			Kg/kg MTBE	0	
	Natural Gas	Kg/kg MTBE	0			Kg/kg MTBE	0	
	Coal	Kg/kg MTBE	0			Kg/kg MTBE	0	
29.0183	Methanol	Gal/Gal MTBE	0.79		5	Kg/kg MTBE	0.844445946	

US Petroleum refining "Meeting Requirements for Cleaner Fuels and Refineries"

58.123	Isobutylene	Gal/Gal MTBE	0.34		5	Kg/kg MTBE	0.273010811	National Petroleum Counc Vol1, Aug 1993	pg148
	Ion exchange resin (acidic)	Kg/kg MTBE	0	?		Kg/kg MTBE	0		
	Air	Kg/kg MTBE	0			Kg/kg MTBE	0		
	Water	Kg/kg MTBE	0			Kg/kg MTBE	0		

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.	
TSP	Kg/kg MTBE	0			Kg/kg MTBE	0		
SOx	kg/kg MTBE	0			Kg/kg MTBE	0		
NOx	kg/kg MTBE	0			Kg/kg MTBE	0		
Cl2	kg/kg MTBE	0			Kg/kg MTBE	0		
CO2	kg/kg MTBE	0		3	Kg/kg MTBE	0		
MTBE	kg/kg MTBE	8.76E+03			Kg/kg MTBE	7.31922E-06		Industrial practice is to leave excess C
Methanol	kg/kg MTBE	2.56E+04			Kg/kg MTBE	2.13838E-05		
Ammonia	kg/kg MTBE	4.90E+00			Kg/kg MTBE	4.09116E-09		
HC total	kg/kg MTBE	0			Kg/kg MTBE	0		
Heavy meta(Cd+Ni+Cr)	kg/kg MTBE	0			Kg/kg MTBE	0		

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.	
COD	lb/Exxon +Glob	0		5	Kg/kg MTBE	0		
BOD	lb/Exxon +Glob	0		5	Kg/kg MTBE	0		
Acid, H+ (Phosphoric)	lb/Exxon +Glob	0		5	Kg/kg MTBE	0		
Metal ions	lb/Exxon +Glob	0		5	Kg/kg MTBE	0		
Cl2	lb/Exxon +Glob	0		5	Kg/kg MTBE	0		
CO2	lb/Exxon +Glob	0		5	Kg/kg MTBE	0		
MTBE	lb/Exxon +Glob	3.90E+01		5	Kg/kg MTBE	3.25744E-08		
Methanol	lb/Exxon +Glob	6.50E+03		5	Kg/kg MTBE	5.42907E-06		
Ammonia	lb/Exxon +Glob	198.5930435		5	Kg/kg MTBE	1.65873E-07		Exxon plant uses ammonia predominantly for other purposes
Heavy metals (Cadmium, Ni	db/Exxon +Glob	0		5	Kg/kg MTBE	0		

Solid waste

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Production waste (not innert)	lb/Exxon +Glob	0		5	Kg/kg MTBE	0	
Heavy metals (Cadmium, Ni	db/Exxon +Glob	0		5	Kg/kg MTBE	0	

Offsite Transfer

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Chromium (catalyst?)	lb/Exxon +Glob	541580			Kg/kg MTBE	0.00045235	

Sheet End ======== ============ =========== =========== =========== =========== ============= ============ =========== ================== ======== ========

Sheet Title: Corn Production   Last Modified   10/06/95

Sheet Description:

This page includes calculations of the average resource consumption and emissions from the production of corn in the United States. This includes information on the embodied energy in materials used such as fertilizers, pesticides and insecticides, lime, and seed.
It does not include embodied energy to manufacture farm machinery or buildings.
All basic data is converted into units of input or output per bushel (bu) of corn output.

Many of the calculations below are adjusted to account for the relationship of harvested to planted acres. Typically, only about 98-99% of planted corn acres are harvested. Some resources have gone into this planting however, such as seed, fertilizer, energy, etc. For this reason, yields and resource consumption are adjusted to account for unharvested acreage.

Air emissions are also broken out by source in the columns to the right of the allocated emissions. These are expressed both as quantity per bushel, and as a percentage of total emissions. In this way the most important sources of air emissions can be identified, and the veracity of the estimates checked.

Also provided in a table to the right are some other recent estimates of energy use to produce corn, and a discussion of why the results of the studies vary. Fortunately, though estimates of energy use for particular inputs vary considerably, this variation in most cases is cancelled out, that the overall energy intensity values are fairly consistent. It is hoped that the detailed methodology followed below is not only accurate, but resource use data important to the assessment of secondary impacts (e.g. emissons from fertilizer manufacture).

Note: Blanchard estimates that 1-3% of corn is removed in the cleaning process at the mill. Since this corn is used in feed, the corn balance presented in the corn refining material balance accounts for this loss.

Energy Use in Corn Production

Item	Study Shapouri et al	Lorenz et al 19	This Study
Nitrogen	22,631	28,295	23,866
Potash	539	2,390	956
Phosphate	1,992	2,417	1,635
Lime	1,232	-	748
Chemicals	5,766	2,704	2,697
All Other	23,024	33,386	24,049
Total	55,184	69,192	53,952

Notes: Both this study and Shapouri rely on the same source of information for on-farm energy us
use is lumped into the category "other" and it can be seen that the two estimates are very close. S
for pesticides from Pimentel (1991) which appears to find its genesis in another Pimentel work (19
to come from Pimentel 1991, but may come from Pimentel 1988, where it is cited at 100 KJ/kg. C
that it includes energy for formulation, packaging, and transport. Shapouri adds energy use for inp
counting. The 1980 estimate for packaging, formulation, and transport is also much higher than co
use at least some fairly crude assumptions about distances and modes hauled. Lacking further in
as consistent with the estimate in Lorenz, and probably derives from the same original data. Energ
quantify precisely. Each form of fertilizer requires different amounts of energy. Both Shapouri and
that were aggregated up from fertilizer type specific data. In this report fertilizer type specific data
the types of fertilizers used with corn to develop a corn specific value. In any case, the estimates
higher than those used by Shapouri and this report, however they include transportation, packagi
The packaging, transportation, and application estimates were derived from a source specifically
fertilizer is sold in bulk, these estimates themselves may be high. Lorenz also uses a very high es
from an estimate that 16% of corn is irrigated. Both this report and the Shapouri report use data fr
use (including irrigation). Since the fraction of corn irrigated in the midwest is very small, this may
intensity estimates.

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Summary Output:

Allocated LCI components		Units	Quantity	DQI	Notes:
Air	Fertilizer N20	lb/bu	0.0132	3	Survey of study results.
	Fertilizer NO	lb/bu	0.0081	1	Based on only one study.
	NOx	lb/bu	4.26E-02	2	Some general emisson factors used
	SOx	lb/bu	2.03E-02	2	Some general emisson factors used
	PM-10	lb/bu	3.62E-01	3	Driven by fugitive emissions from tilling for which current data is available.
	CO	lb/bu	1.53E-01	4	Driven by CO emission from gas tractors for which current data is available.
	CO2	lb/bu	6.93E+00	4	Good quality data
	Non-Methane Organic C	lb/bu	2.33E-02	3	Dominated by VOC's used in pesticides. Relatively well characterized.
	Methane	lb/bu	1.98E-05	2	Some general emisson factors used
	Particulate	lb/bu	4.48E-03	2	Some general emisson factors used
	Hydrocarbons	lb/bu	1.00E-02	3	Fairly current and specific data on farm machinery emissions.
	Aldehydes	lb/bu	4.70E-04	3	Fairly current and specific data on farm machinery emissions.
	Ammonia	lb/bu	1.42E-02	2	Dominated by emissions from ammonium nitrate manufacture, for which factors given as a very broad range. Thus point estimate may be poor.
	Nitric Acid	lb/bu	1.97E-04	2	Dominated by emissions from ammonium nitrate manufacture, for which factors given as a very broad range. Thus point estimate may be poor.
	Fluoride	lb/bu	1.79E-05	4	AP-42 Emission Factor based. Data quality rating excellent.
	Acid Mist	lb/bu	1.01E-03	2	AP-42 Emission Factor based. Data quality rating poor.
	Herbicides	lb/bu	5.06E-03	2	Emission factor rating poor.
	Alachlor	lb/bu	1.01E-03	2	Emission factor rating poor.
	Atrazine	lb/bu	1.86E-03	2	Emission factor rating poor.
	Metalachlor	lb/bu	1.23E-03	2	Emission factor rating poor.
	Cyanazine	lb/bu	9.62E-04	2	Emission factor rating poor.
	Insecticides	lb/bu	8.01E-04	2	Emission factor rating poor.
	Fonofos	lb/bu	1.49E-04	2	Emission factor rating poor.
	Turbufos	lb/bu	3.95E-04	2	Emission factor rating poor.
	Chlorpyrifos	lb/bu	2.57E-04	2	Emission factor rating poor.
Water	Herbicides	lb/bu	1.97E-04	3	These four herbicides make up 80% of the total herbicide use (out of a total of 26 herbicides) in corn production
	Alachlor	lb/bu	8.82E-06		
	Atrazine	lb/bu	9.55E-05		
	Metalachlor	lb/bu	3.88E-05		

	Cyanazine	lb/bu	5.36E-05		
	Insecticides	lb/bu	1.67E-05	2	There is little data on insecticide loss
	Fonofos	lb/bu	2.57E-06		These three insecticides make up 75%
	Turbufos	lb/bu	6.81E-06		of total insectide use in corn production.
	Chlorpyrifos	lb/bu	7.34E-06		
	Nitrates (as nitrogen)	lb/bu	0.16	3	Other sources of nitrogen contribute to nitrate loading
	Phosphorous	lb/bu	3.92E-03		
	Potassium	lb/bu	0.02		
Resource Co	N.G.	Btu/bu	28,391	4	Energy use estimates derived from current data and are consistent with other results.
	Diesel	Btu/bu	11,393	4	Energy use estimates derived from current data and are consistent with other results.
	LPG	Btu/bu	3,210	4	Energy use estimates derived from current data and are consistent with other results.
	Coal	Btu/bu	522	4	Energy use estimates derived from current data and are consistent with other results.
	Oil	Btu/bu	1,870	4	Energy use estimates derived from current data and are consistent with other results.
	Gasoline	Btu/bu	3,621	4	Energy use estimates derived from current data and are consistent with other results.
	Electricity	Kwh/bu	0.494	4	Energy use estimates derived from current data and are consistent with other results.
	Total Fuel	Btu/bu	49,007		
	Limestone	lb/bu	1.28	4	Current data but some conflicting estimates.
	Sulfur	lb/bu	0.436	5	Current data.
	Water	gallons/bu	8,863	3	Derived from average irrigation practices.
	Phosphate Rock	lb/bu	1.253	5	Current data.
	Potassium Chloride	lb/bu	0.367	5	Current data.
	Soil	lb/bu	96	3	Total Loss of Soil. See Table 4.

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source:	
bu	lb	56	lb_bu		
Hectares	acre	2.47	acre_hect	22	
kg	lb	2.20	lb_kg	22	
hectares	sq. meters	10,000	sqmeters_hect	22	
meter	feet	3.28	feet_meter	22	
short tons	lb	2,000	lb_shortton	22	
metric tons	kg	1,000	kg_mton	22	
kcal	btu	3.97	btu_kcal	22	
Joules	btu	9.47E-04	btu_joule	22	
Gallons Etha	lb	6.58	lb_gallon	46	Specific Gravity = .7893
Gallons Etha	bu	0.4	bu_gallon	12	Depending on plant and process may range from .385 to .40.
Hectares	Sq. cm	1.00E+08	sqcm_ha	22	
cubic cm	liters	0.001	liters_ccm	22	
liters	gallons	0.264	gallons_liter	22	
sq mile	acres	640	acres_sqmile	22	
metric tons	short tons	1.102	shortton_metricto	22	
barrels	gallons	42	gallons_barrel	22	
kg	grams	1,000	grams_kg	22	
cubic foot na	btu	1,032	btu_cubicft	38	
barrel distilla	million btu	5.825	btu_barreloil	38	
barrel motor	million btu	5.253	btu_barrelgas	38	
Short ton coa	million btu	22.25	Btu_toncoal	38	
Barrel LPG	million btu	3.614	Btu_barrellpg	38	86,048
Gallons Wate	lb	8.337	lb_gallonw	22	

Molecular W	Element/Com	Name	Wt.	Defined Name

H	Hydrogen	1.008
Ca	Calcium	40.08
O	Oxygen	16.00
S	Sulfur	32.06
C	Carbon	12.01
Cl	Chlorine	35.45
K	Potassium	39.10
P	Phosphorus	30.97
N	Nitrogen	14.01
K_2O	Potash	94.20
KCl	Muriate of Potash	74.56
CO_2	Carbon Dioxide	44.01
$CaSO_4$	Calcium Sulfate	136.14
H_2SO_4	Sulfuric Acid	98.07
P_2O_5	Phosphoric Acid	141.94
HNO_3	Nitric Acid	63.01
NH_4NO_3	Ammonium Nitrate	80.04

Ratio CO_2:C	3.66	carbon_ratio
Ratio K_2O:KCl	1.26	Potassium_ratio
Ratio H_2SO_4:S	3.06	Sulfur_acid
Ratio S:P_2O_5	0.23	sulfur_Pratio
Ratio 2N:NH_4NO_3	0.35	N_ammonitrate
Ratio HNO_3:NH_4NO_3	0.79	
Ratio N:NH_3	0.82	Ammonia_ratio
Ratio H_2SO_4:P_2O_5	0.69	

Calculations --

Table 1 Corn Yield per Acre Planted (k acres and bushels/acre)

United States Department of Agriculture
National Agricultural Statistics Service
Crop Production: 1994 Summary
Cr Pr 2-1(95)
January 1995 Area in thousands of acres

LCI component	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	10 - Year Avera	6 - Year Aver	4 - Year Average
Area Planted	83,398	76,580	66,200	67,717	72,322	74,166	75,957	79,311	73,235	79,158	74,804	75,692	76,915
Area Harvest	75,209	68,907	59,505	58,250	64,783	66,952	68,822	72,077	62,921	72,917	67,034	68,079	69,184
Area Harvest	7,155	6,418	5,994	8,301	6,606	6,123	6,140	6,069	6,831	5,563	6,520	6,222	6,151
Total Area H	82,364	75,325	65,499	66,551	71,389	73,075	74,962	78,146	69,752	78,480	73,554	74,301	75,335
Fraction of A	98.76%	98.36%	98.94%	98.28%	98.71%	98.53%	98.69%	98.53%	95.24%	99.14%	98.32%	98.14%	97.90%
Yield (Corn fo	118	119.40	119.80	84.6	116.30	118.5	108.6	131.5	100.7	138.60	115.6	119.0	119.9
Adjusted Yiel	116.5	117.4	118.5	83.1	114.8	116.8	107.2	129.6	95.9	137.4	113.7	116.9	117.5

Notes: Data in bolded rows are from the USDA publication. Since energy is invested in all planted acreage, corn yields are adjusted to the yield per planted acre by multiplying by the fraction of planted acres harvested in any given year. The average yield has been increasing over time. In order to most accurately describe current yields, average yields over the past 20 years can be fit with a simple linear model. The data are converted to a base year of 1975, so that year 1 represents 1975, and year 20 represent 1994. Based on this model (presente 120.54 bu/acre.
This value is stored in the variable yield, and is used throughout this spreadsheet.

Model	R squared = .3859	F test
Intercept	89	0.0001
Year (1 - 20)	1.68	0.0035

Predicted Yie	Quantity	Units	Adjusted Yield (to account for fraction of planted acreage that is harvested)
1992	119.2	Bu/acre	117.2
1993	120.9	Bu/acre	118.9

1994 122.6 Bu/acre 120.5

Table 2 Chemical Usage in Corn Production

(1) Agricultural Chemical Usage: (Year) Field Crop Summary
United States Department of Agriculture, National Agricultural Statistics Service
Ag Ch 1 (yr)

LCI component	Raw/ Input Quan.	Raw/ Input Quan.	Raw/ Input Quan.	Raw/ Input Quan.	DQI	Transformed Quan.	Transformed Quan.	Transformed Quan.	Transformed Quan.	Raw Average	Transformed Average
Year	1991	1992	1993	1994		1991	1992	1993	1994		
Raw/Input Units	(MM lbs)	(MM lbs)	(MM lbs)	(MM lbs)		(lbs/acre)	(lbs/acre)	(lbs/acre)	(lbs/acre)	(MM lbs)	(lbs/acre)
Fertilizers											
Nitrogen	8,447	8,902	7,956	7,856	10	123	125	121	126	8,290	123.7
Phosphate	3,331	3,344	2,995	2,992	10	49	47	46	48	3,166	47.2
Potash	3,910	3,950	3,519	3,603	10	57	55	54	58	3,746	55.9
	(thousand lbs)	(thousand lbs)	(thousand lbs)	(thousand lbs)		(lbs/acre)	(lbs/acre)	(lbs/acre)	(lbs/acre)		
Herbicides											
2,4-D	2,800	2,832	3,586	3,631	10	0.041	0.040	0.055	0.058	3,212	0.048
Acetochlor				7,447	10	0.000	0.000	0.000	0.119	1,862	0.030
Alachlor	37,174	40,129	32,078	21,325	10	0.542	0.562	0.488	0.341	32,677	0.483
Ametryn	59	146			10	0.001	0.002	0.000	0.000	51	0.001
Atrazine	52,060	54,939	49,553	45,412	10	0.759	0.769	0.754	0.727	50,491	0.752
Bentazon	478	550	497	584	10	0.007	0.008	0.008	0.009	527	0.008
Bromoxynil	1,344	1,389	1,364	1,446	10	0.020	0.019	0.021	0.023	1,386	0.021
Butylate	8,478	8,117	5,441	2,117	10	0.124	0.114	0.083	0.034	6,038	0.088
Cyanazine	23,161	26,691	26,453	27,689	10	0.338	0.374	0.403	0.443	25,999	0.389
Dicamba	3,556	5,068	4,598	6,322	10	0.052	0.071	0.070	0.101	4,886	0.073
Dimethenamid				2,241	10	0.000	0.000	0.000	0.036	560	0.009
EPTC	14,355	10,594	11,098	6,124	10	0.209	0.148	0.169	0.098	10,543	0.156
Flumetsulam				52	10	0.000	0.000	0.000	0.001	13	0.000
Glyphosate	1,156	746	1,973	1,776	10	0.017	0.010	0.030	0.028	1,413	0.021
Imazethapyr			11	37	10	0.000	0.000	0.000	0.001	12	0.000
Linuraon	93	96			10	0.001	0.001	0.000	0.000	47	0.001
Metolachlor	38,792	41,327	39,026	39,213	10	0.565	0.579	0.594	0.627	39,590	0.591
Metribuzin			46	41	10	0.000	0.000	0.001	0.001	22	0.000
Nicosulfuron	75	140	165	249	10	0.001	0.002	0.003	0.004	157	0.002
Paraquat	201	423	630	400	10	0.003	0.006	0.010	0.006	414	0.006
Pendimentalin	2,745	3,091	2,825	1,806	10	0.040	0.043	0.043	0.029	2,617	0.039
Primisulfuron	29	30	40	47	10	0.000	0.000	0.001	0.001	37	0.001
Propachlor	1,456	1,506	1,260	1,184	10	0.021	0.021	0.019	0.019	1,352	0.020
Simazine	1,081	1,147	1,118	972	10	0.016	0.016	0.017	0.016	1,080	0.016
Tridiphane	264	123		66	10	0.004	0.002	0.000	0.001	113	0.002
Trifluralin	111		114		10	0.002	0.000	0.002	0.000	56	0.001
Total Herbicide	189,468	199,084	181,876	170,181		2.76	2.79	2.77	2.72	185,152	2.760
	(thousand lbs)	(thousand lbs)	(thousand lbs)	(thousand lbs)		(lbs/acre)	(lbs/acre)	(lbs/acre)	(lbs/acre)		
Insecticides											
Bifenthrin	14	4			10	0.0002	0.0001	0.0000	0.0000	5	0.0001
Bacillus thur.	2,094			326	10	0.0305	0.0000	0.0000	0.0052	605	0.0089
Carbofuran	2,278	1,648	1,133	326	10	0.0332	0.0231	0.0172	0.0052	1,346	0.0197
Chlorpyrifos	6,716	6,247	5,584	5,206	10	0.0979	0.0875	0.0850	0.0833	5,938	0.0884
Diazinon	116	74			10	0.0017	0.0010	0.0000	0.0000	48	0.0007
Dimethoate	78	74			10	0.0011	0.0010	0.0000	0.0000	38	0.0005

Esfenvalerate	12	8			10	0.0002	0.0001	0.0000	0.0000	5	0.0001
Flucythrinate	6				10	0.0001	0.0000	0.0000	0.0000	2	0.0000
Fonofos	2,890	2,044	1,876	1,549	10	0.0421	0.0286	0.0286	0.0248	2,090	0.0310
Methyl Parathion	812	557	635	738	10	0.0118	0.0078	0.0097	0.0118	686	0.0103
Permethrin	207	202	155	222	10	0.0030	0.0028	0.0024	0.0036	197	0.0029
Phorate	1,306	990	1,448	895	10	0.0190	0.0139	0.0220	0.0143	1,160	0.0173
Propargite	146				10	0.0021	0.0000	0.0000	0.0000	37	0.0005
Tefluthrin	244	187	246	242	10	0.0036	0.0026	0.0037	0.0039	230	0.0034
Terbufos	5,986	6,309	5,561	4,270	10	0.0873	0.0884	0.0846	0.0683	5,532	0.0821
Trimethacarb	121	132			10	0.0018	0.0018	0.0000	0.0000	63	0.0009
Total Insecticide										17,979	0.2670

Notes: The data given below indicates the number of states from which the agricultural chemical usage data was developed, and the percentage of planted area which those states represent for corn.

Year	1991	1992	1993	1994	15
States Covered	17	17	16	10	87%
Percentage of Area	90%	90%	90%	79%	67.05
Area Planted (MM Acres)	68.6	71.4	65.7	62.5	

Table 3 Seed Consumption

United States Department of Agriculture, Economic Research Service
Agricultural Resources, Inputs: Situation and Outlook Report, AR-32, 1993

United States Department of Agriculture
National Agricultural Statistics Service
Crop Production: 1994 Summary
Cr Pr 2-1(95)
January 1995

LCI Compon Crop Year	Seed	Seed (lb)	Seed (MMBu	Area Planted	Seed/acre	Seed/acre	Seed/bu
Units	Th. short ton	lb	million bushe	thousand acre	lb/acre	kg/ha	lb/bu
1989/90	529	1,058,000,000	18.89	74,166	14.27	15.99	0.118
1990/91	540	1,080,000,000	19.29	75,957	14.22	15.94	0.118
1991/92	566	1,132,000,000	20.21	79,311	14.27	16.00	0.118
1992/93	524	1,048,000,000	18.71	73,235	14.31	16.04	0.119
Average					14.27	15.99	0.118

Notes: Seed use in bold from source 1, area planted in bold from source 2, the data for which are in table 1. Four year average value converted to seed use per bushel using the estimated yield in table 1.

Table 4 Erosion from Cropland and Corn Cropland

(1) United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

(2) Kellog, R.L., and S. Wallace. 1995. Erosion Estimates and the Effects of Land Use Changes on Soil Savings Estimates - Insights from the 1992 National Resources Inventory, Poster Board Presented at the 50th Annual Meeting of the Soil and Water Conservation Society, August 6-9, 1995, Des Moines, Iowa.

LCI Component	Erosion weighted by production

Erosion By State and Type (1)

Units	Raw/ Input Quan. (tons/acre/yr)	Raw/ Input Quan. tons/acre/yr)	Raw/ Input Quan. (tons/acre/yr)	(million bushe	(million bushels)		Transformed Quan.			Erosion per Bushel (tons/bu)	Erosion per Bushel (lb/bu)
State	Sheet/Rill Erosion	Wind Erosion	Total Erosion	1994 Producti	Cumulative	Cum. Fraction	Sheet/Rill Ero	Wind Erosion	Total Erosion		
Iowa	5.6	1.4	7	1,930,400	1,930,400	19.11%	10,810,240	2,702,560	13,512,800		
Illinois	4.4	0	4.4	1,786,200	3,716,600	36.79%	7,859,280	0	7,859,280		
Nebraska	3.6	1.7	5.3	1,153,700	4,870,300	48.21%	4,153,320	1,961,290	6,114,610		
Minnesota	2.4	6.3	8.7	915,900	5,786,200	57.27%	2,198,160	5,770,170	7,968,330		
Indiana	3.4	0.4	3.8	858,240	6,644,440	65.77%	2,918,016	343,296	3,261,312		
Ohio	3.3	0.1	3.4	486,500	7,130,940	70.58%	1,605,450	48,650	1,654,100		
Wisconsin	4.1	0.3	4.4	437,100	7,568,040	74.91%	1,792,110	131,130	1,923,240		
South Dakota	2.3	2.7	5	367,200	7,935,240	78.54%	844,560	991,440	1,836,000		
Kansas	2.3	2.1	4.4	304,590	8,239,830	81.56%	700,557	639,639	1,340,196		
Total	31.4	15	46.4	10,103,000			32,881,693	12,588,175	45,469,868		
Average	3.49	1.67	5.16				3.25	1.25	4.50	0.04	74.68
							54.00	20.67	74.68		

Erosion by C	Raw/ Input Quan.	Raw/ Input Quan.	Raw/ Input Quan.	
	Sheet/Rill Erosion	Wind Erosion	Total Erosion	Units
Land Planted	4.4	1.3	5.7	tons/acre/year
Highly Erodib	11.2	2.2	13.4	tons/acre/year
Not Highly Er	2.5	1.1	3.6	tons/acre/year
All Corn Land	4.3	1.5	5.8	tons/acre/year
Highly Erodib	10.8	2.3	13.1	tons/acre/year
Not Highly Er	2.5	1.2	3.7	tons/acre/year
All Corn Land	71.35	24.89	96.23	lb/bu

Notes: Bob Kellog provided this disaggregated data. Soil loss cannot be treated simply as a resource cost, since soil is naturally regenerated over time. This is usually quantified as the soil loss tolerance, usually somewhere between 4 and 5 tons/acre/year. The corn land soil loss estimate used here is slightly above this value, indicating that some degradation of corn cropland is occurring. Soil losses have been decreasing steadily in the past decade, however, indicating that average losses will soon be in the soil loss tolerance range.

Table 5 Water Use in Irrigation

(1) United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

(2) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

(3) United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

(4) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

Weighting Data

State	1994 Production (3)	Cumulative	Cum. Fraction	Raw/ Input Quan. (acres) Irrigated	Raw/ Input Quan. (acres) Non-Irrigated	Raw/ Input Quan. (acres) Total	Percentage	Requirements (4) (cm)	Weighted by % irrigated	Times Production

	(million bushels)	(million bushels)									
Iowa	1,930,400	1,930,400	19.11%	143.9	23,222	23,366	0.00%		52.07	0.00	0
Illinois	1,786,200	3,716,600	36.79%	196	22,984	23,180	0.00%		52.07	0.00	0
Nebraska	1,153,700	4,870,300	48.21%	6923.2	10,510	17,433	76.00%		50.80	38.61	44,542,050
Minnesota	915,900	5,786,200	57.27%	434	18,312	18,746	2.32%		52.07	1.21	1,104,098
Indiana	858,240	6,644,440	65.77%	174.2	12,582	12,756	8.00%		52.07	4.17	3,575,085
Ohio	486,500	7,130,940	70.58%	27.5	10,144	10,172	0.00%		52.07	0.00	0
Wisconsin	437,100	7,568,040	74.91%	334	6,714	7,048	5.00%		52.07	2.60	1,137,990
South Dakota	367,200	7,935,240	78.54%	389.4	13,514	13,904	29.00%		52.07	15.10	5,544,830
Michigan	260,910	8,196,150	81.13%	3209	21,698	24,907	9.00%	(kansas)	53.34	4.80	1,252,525
Total	10,103,000			11,831	139,680	151511.1	7.81%			66.48	57,156,576

Note: This calculation was originally made form reference 1. More accurate data was available in reference 2, however, so where applicable these values were substituted into the fraction of acreage irrigated column. In general the estimates from reference 1 were good for states using little or no irrigation, but somewhat low for states using significant amounts of irrigation. Data from reference 2 has been retained as it is used for one state, Minnesota, for which a value is not given in reference 2. Irrigation rates are taken from reference 4 for Nebraska and and Kansas. The average average of these two values is applied to the other states. From this data a weighted average water use value is calculated, which represents the average amount of water used in irrigation per bushel of corn grown. Thus the value is far below the actual amount used in irrigated corn, and reflects the fact that most corn is not irrigated.

Weighted	
Average (cm)	6.97
cubic cm/Ha	697,358,837
liters/ha	697,359
gallons/ha	2,639,811
gallons/acre	1,068,300
gallons/Bu	8,863

Table 6 Lime and Sulfur Consumption

(1) United States Department of Agriculture. 1993. Agricultural Resources: Inputs: Situation and Outlook Report, USDA Economic Research Service, AR-32.

	Area (MM acres)	Applied (%)	Rate (lb/acre)	Total (MM lbs)	Rate (adj) (lb/acre)	Rate Planted (lb/acre)	Rate (lb/Bu)	Energy (Btu/lb)	Energy Btu/bu)
Lime	62.85	4%	3800	9553.2	152	154.60	1.28	568	727.90
Sulfur	62.85	11%	11	76.0485	1.21	1.23	0.01	1997	20.39

Notes: The ERS publishes information on the use of lime and sulfur in corn production. They give an application rate in lb/acre for acreage that is treated. This can be converted into an overall average application rate per acre by dividing total applied material by the total planted area. This value must then be converted to account for the fact that not all planted acreage is harvested. This is done by dividing by the harvested fraction (defined variable fraction). Finally the value is converted to units of lb/bushel using the average yield (defined variable yield).

Table 7 Energy Use in the Production of Fertilizer

(1) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(3) The Fertilizer Institute. 1982. The Fertilizer Handbook

(4) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(5) Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(6) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(7) The Fertilizer Institute. 1987. Fertilizer Energy Use Survey.

(8) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(9) Kirk-Othmer. 1982. The Encyclopedia of Chemical Technologies, Vol. 10, "Fertilizers".

Energy Requirements for Fertilizer Production (GJ/metric ton fertilizer)

	Natural Gas	Electricity	Oil	Steam	Exported Stea	Total
Anhydrous A	40.79	1.1	0	0	0.38	41.51
Urea	26.02	2.55	0	3.7	0.81	31.46
Nitrogen Solu	16.11	1.02	0	0.63	0.37	17.39
Triple Superp	0.54	2.51	0.55	1.89	2.35	3.14
Potash (as K	2.69	2.11	0	0	0	4.8

Notes: Taken from Table 16 of reference 4 (p. 26).

Energy Requirements for Fertilizer Production (Btu/lb except electricity, which is kwh/lb)

	Natural Gas	Electricity	Oil	Steam	Exported Stea	Total (Btu/lb)	Total (kwh/lb)
Anhydrous A	17,523	0.047	0	0	163	17,360	0.047
Urea	11,178	0.110	0	1,590	348	12,420	0.110
Nitrogen Solu	6,921	0.044	0	271	159	7,033	0.044
Triple Superp	232	0.108	236	812	1,010	271	0.108
Potash (as K	1,156	0.091	0	0	0	1,156	0.091

Notes: Reference 7 gives the original survey data, and says that electricity is converted to btu using the convention of 10,000 btu/kwh (i.e. accounting for losses). I have converted back to kwh.

Nutrient Content of Fertilizers

		Source:
Anhydrous A	82% Nitrogen	4
Urea	46% Nitrogen	4
Nitrogen Solu	30% Nitrogen	4
Triple Superp	46% P2O5	4
Potash (as K	100% K2O	4

Notes: Reference 4 uses these nutrient contents. Reference 3 uses 44 to 46% for triple superphosphate, and 28 to 32% for nitrogen solutions. We follow the convention of reference 4.

Energy Requirements for Fertilizer Production (Btu/lb nutrient)

	Natural Gas	Electricity	Oil	Steam	Exported Stea	Fuel Total (Btu/lb)	Electricity Total (kwh/lb)	Electricity (Btu/lb)	Total (Btu/lb)
Anhydrous A	21,370	0.058	0	0	199	21,171	0.058	576	21,747
Urea	24,300	0.238	0	3,455	756	26,999	0.238	2,381	29,381
Nitrogen Solu	23,069	0.146	0	902	530	23,442	0.146	1,461	24,902
Triple Superp	504	0.234	514	1,765	2,195	588	0.234	2,344	2,932
Potash (as K	1,156	0.091	0	0	0	1,156	0.091	906	2,062

Notes: Reference 8 cites the Fertilizer Institute for energy consumption estimates of 22,159 Btu/lb nitrogen, 4,175 Btu/lb P2O5, and 1,245 Btu/lb potash. The nitrogen estimate is close to what reference 4 gets here, but differs significantly for the other fertilizers. Examination of reference 7 reveals that the estimate for potash seems to come from a 1985 survey by the Fertilizer Institute. The value given is 2,489 kbtu/ton potash. This converts to 1,245 Btu/lb of potash. Reference 4 uses this data, plus fuel breakouts from a 1979 survey, but then converts to K2O assuming that the energy use value is for muriate of potash, and that muriate of potash is 60% K2O. This yields our value of 2,065 Btu/lb K2O. Since most references cite potash consumption for agricultural uses in terms of weight of K2O, it is not clear whether reference 8 has used an appropriate energy intensity figure.

Estimating energy use in phosphate production is confused by the fact that sulfuric acid production is highly exothermic. If all of this energy is counted towards phosphoric acid production, in some cases the total energy use is still negative. The estimates given in reference 7, and used by reference 4 seem to exclude energy use in sulfur mining. Reference 3 however, includes energy use in sulfur mining, and cites a total energy consumption

of 7,200 btu/lb P2O5 for triple superphosphate. Reference 9 also gives a fairly high figure of 5,500 btu/lb P2O5 for triple superphosphate. Some estimates are given below.

Energy Intensity of Phosphate Fertilizer Production

Raw Input Qu	Units	Source	Tranformed Inpu	Units	Electricity	Natural Gas	Oil		Units
7,200	Btu/lb P2O5	(3)	7,200	Btu/lb K2O5					
2,300	kcal/kg P2O5	(1)	4,140	Btu/lb K2O5					
12.79	GJ/ton P2O5	(9)	5,495	Btu/lb K2O5					
4,175	Btu/lb P2O5	(8)	4,175	Btu/lb K2O5	1,962	1,086		1,127	Btu/lb
					0.196				kwh/lb

Notes: Reference 3 is very high, however Fertilizer Institute surveys suggest that the energy use for P2O5 production dropped in half from the 1979 to the 1983 survey (as cited in reference 4) suggesting that modern production processes would be in line with other estimates. Lacking a better method I will use the value cited in reference 8, from the Fertilizer Institute, and assume that this is the best representation of average U.S. practices.

Energy Requirements for Fertilizer Production (Btu/lb nutrient)

	Natural Gas	Electricity (Kw	Oil	Total Fuel	Total (kwh at	Fraction of Fuels Natural Gas	Fuel Oil
Anhydrous A	21,171	0.058	0	21,171	21,747	100%	0%
Urea	26,999	0.238	0	26,999	29,381	100%	0%
Nitrogen Solu	23,442	0.146	0	23,442	24,902	100%	0%
Phosphates	1,086	0.196	1,127	2,213	4,175	49%	51%
Potash	1,156	0.091	0	1,156	2,062	100%	0%

Table 8 Energy Use for Fertilizer Packaging and Transportation

(1) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(2) Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(3) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

Energy Use for Packaging and Transportation

	Nitrogen	Phosphorous	Potash	Units
Packaging	2.58	2.65	1.75	GJ/mt
Transportatio	4.47	5.68	4.60	GJ/mt
Total	7.05	8.33	6.35	GJ/mt

	Nitrogen	Phosphorous	Potash	Units
Packaging	1,108	1,138	752	Btu/lb
Transportatio	1,920	2,440	1,976	Btu/lb
Total	3,029	3,579	2,728	Btu/lb

Notes: This data is used by reference 1 to estimate packaging and transportation energy use for fertilizers. Reveiwing the source, however, this data was generated with particular reference to international applications, and thus may not be representative of U.S. average practices, especially for transportation. By comparison, the energy needed to make packaging material is quite small (see below). Also, most fertilizer is shipped in bulk in the U.S. (also below). Anhydrous ammonia, which is the most important form of nitrogen use for corn in Iowa, is also the least energy intensive to transport (pipeline). Thus it will be assumed that the energy use to package fertilizers for corn use is negligible. Transportation energy use estimates are included in the estimates of direct energy use on the farm, and are derived from Shapouri et al 1995.

Energy Use for 50 Kg Polyethylene Plastic Fertilizer Bags (3)

	420 MJ/metric ton	180 Btu/lb

Consumption of Fertilizer by Class in the U.S. 1992

	Short tons	
Dry Bulk Sing	12,313,103	94% of single nutrient is bulk
Dry Bagged S	742,949	6%
Total Dry Sin	13,056,052	
Dry Bulk Mul	10,949,818	78% of multinutrient is bulk
Dry Bagged M	3,126,493	22%
Total Dry Mu	14,076,310	
Total Fluid	18,085,682	40% of total is liquid
Total	45,218,045	

Table 9 Energy Use in the Production of Herbicides and Insecticides

(1) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1994. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(2) Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

(3) Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

(4) Green, M.B. 1987. Energy in Pesticide Manufacture, Distribution and Use, in Energy in World Agriculture, Energy in Plant Nutrition and Pest Control, Volume 2, Z.R. Helsel (ed.), Elsevier Press, New York.

Energy Intensity of Pesticide Production (per unit a.i) (4 and 1)

Herbicide	Energy Intensity (GJ/tor	Energy Inten	Use Rate (lb/bu)	Energy Int. x Use Rate
2,4-D	85	36,516	4.01E-04	14.63
Alachlor	278	119,428	4.01E-03	478.89
Atrazine	190	81,623	6.24E-03	509.42
Bentazon	434	186,445	6.55E-05	12.21
Bromoxynil	150	64,440	1.72E-04	11.09
Butylate	141	60,573	7.34E-04	44.47
Chlorsulfuron	365	156,803		0.00
Cyanazine	201	86,349	3.23E-03	278.86
Dicamba	295	126,731	6.10E-04	77.26
Diuron	270	115,991		0.00
EPTC	160	68,736	1.30E-03	89.03
Fluazifop-me	518	222,531		0.00
Glyphosate	454	195,037	1.78E-04	34.69
Isopropalin	150	64,440		0.00
Linuron	290	124,583	5.60E-06	0.70
MCPA	130	55,848		0.00
Methazole	150	64,440		0.00
Metolachlor	276	118,569	4.91E-03	581.76
Metribuzin	200	85,919		0.00
Molinate	150	64,440		0.00
Norflurazon	150	64,440		0.00
Pendimethali	150	64,440	3.22E-04	20.74
Prometryn	200	85,919		0.00
Propanil	220	94,511		0.00
Trifluralin	150	64,440	6.95E-06	0.45
Propachlor	290	124,583	1.67E-04	20.78

Paraquat	460	197,615	5.15E-05	10.18
			0.02	2185.16
		Wt. average Energy Intensity		97,575

Notes: Reference 1 cites reference 4 data, then uses the data to extrapolate to pesticides not covered by reference 4. Reference 1 incorrectly cites the energy intensity of diuron at 200 GJ/mt, instead of 270 GJ/mt from the original reference. The other values are correct. Use rates are from Table 2 of this sheet.

Energy Intensity of Insecticide Production (1 and 4)

Insecticide	Energy Intensity (GJ/tor	Energy Inten	Use Rate (lb/bu)	Energy In. x Use Rate
Chlorpyrifos	250	107,399	7.34E-04	78.78
Fonofos	200	85,919	2.57E-04	22.11
Fensulfothion	200	85,919		0.00
Terbufos	200	85,919	6.81E-04	58.55
Carbofuran	454	195,037	1.63E-04	31.85
Methyl parath	160	68,736	8.53E-05	5.86
Phorate	209	89,786	1.44E-04	12.90
			2.06E-03	2.10E+02
Wt. Average				101,742

Other estimates of Energy Use in Pesticide Production

Insecticide		100,000	kcal/kg	(2)	179,999	Btu/lb
Herbicide		100,000	kcal/kg	(2)	179,999	Btu/lb
Pesticides	Wisconsin	231,000	Btu/acre	(3)	2,265	Btu/bu
	Nebraska	228,000	Btu/acre	(3)	2,092	Btu/bu
	Kansas	245,000	Btu/acre	(3)	2,333	Btu/bu

Table 10 Energy Use in Pesticide Formulation and Packaging

(1) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(2) Green, M. 1987. Energy in Pesticide Manufacture, Distribution, and Use, Energy in Plant Nutrition and Pest Control, ed. Z.R. Helsel, New York, Elsevier, pp. 165-196.

Pesticide Formulation and Packaging
Energy Use

		Raw Input/ Quantity	Raw/ Input Units	Source	Transformed Input Quan.	Transformed Input Units	Notes:	Fuel Types (%) Oil	Gas	Coal
Herbicides	Miscible Oil	41,800	kcal/kg	(1)	75,240	Btu/lb		60%	23%	17%
	Wettable Powder	5,100	kcal/kg	(1)	9,180	Btu/lb		43%	37%	20%
	Granules	23,600	kcal/kg	(1)	42,480	Btu/lb		42%	37%	21%
	Average	23,500	kcal/kg		42,300	Btu/lb		48%	32%	19%
Insecticides	Miscible Oil	41,800	kcal/kg	(1)	75,240	Btu/lb		61%	23%	16%
	Wettable Powder	5,100	kcal/kg	(1)	9,180	Btu/lb		43%	37%	20%
	Granules	23,600	kcal/kg	(1)	42,480	Btu/lb		42%	37%	21%
	Dust	23,600	kcal/kg	(1)	42,480	Btu/lb		42%	37%	21%
	Average	23,525	kcal/kg		42,345	Btu/lb		47%	34%	20%

Pesticides	Miscible Oil	22 GJ/mt	(2)	9,451	Btu/lb
	Wettable Powder	32 GJ/mt	(2)	13,747	Btu/lb
	Granules	12 GJ/mt	(2)	5,155	Btu/lb
	Average	22 GJ/mt	(2)	9,451	Btu/lb

Notes: There is extremely wide variation in pesticide energy intensity estimates. Though pesticide use in corn farming is small on a mass basis, because pesticides are very energy intensive, the overall impact on corn energy use is not insignificant. Lacking a better reason, reference 2 will be used because it is more recent.

Table 11 Energy Use in Seed Production

(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences; Vol. 9, No. 3, pp. 213-233.

(4) Economic Report to the President. 1995. Transmitted to the Congress February 1995, U.S. GPO, Washington, D.C.

(5) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(6) Personal Communication with David Bruch, Gro-Mart Seed Division, Bloomington, IL, Sept. 20, 1995.

Seeding Rate	0.12	lb/bu
	0.0021	lb seed/lb corn

Raw/ Input Quan.	Raw/ Input Units	Source	Transformed Input Quan.	Transformed Input Units	Notes:
186	Btu/Bu	(1)	186	Btu/bu	9-State Average
24,806	Kcal/kg seed	(2)	5,285	Btu/bu	U.S. Average

Notes: Sources (2) and (3) rely on estimates of the energy intensity to propagate crops based on the relative cost of feed corn versus hybrid seed corn. Using 1977 data on the retail cost of corn seed ($0.71/lb) and 1973 energy use per $GNP (15,800 kcal/$), the energy cost is computed at 24,806 kcal/kg. This is the approximate figure which is used in both the referenced sources. Reference 1 is based on the assumption that seed requires 150% of the energy that is required for grain. Neither method is particularly appealing. One relies on very gross assumptions about the relationship of costs and energy consumption in the hybrid corn seed industry, the other is just a guess. Lacking other options, it is at least possible to update the estimates based on energy use per unit gross domestic product. This data is presented below.

Year	Domestic Energy Consu (Quads)	Gross Dome (Billion $)	Ratio Btu/$ GDP	Ratio (Kcal/$ GDP)	Seed Cost ($/80,000 Kernals)	Kernals/lb	Seed Cost ($/ lb)	Energy Intensity (Btu/lb seed)	Energy Intensity (Btu/bu corn)
1991	81.12	5724.8	14,170	3,571	70.2	1300	1.14	16,164	1,913
1992	82.14	6020.2	13,644	3,439	71.8	1300	1.17	15,919	1,884
1993	83.96	6343.3	13,236	3,336	72.7	1300	1.18	15,637	1,851
Average			13,683						1,883

Notes: Accordingly, the current estimate of energy use to produce corn seed is much smaller than the estimate made based on 1970's data. This is due both to a more energy efficient economy (i.e. lower btu/$ GDP) and due to lower seed prices (current prices are equivalent to about $0.45/lb in 1977 dollars). Interestingly, my estimate of the energy intensity of the U.S. economy in 1973 is also about 12% less than the estimate made in reference 2. Combined, current energy intensity estimates are only about 40% of those made based on the 1970's data. The veracity of the gross argument made is also still in question. As a rough check, however, it is interesting to estimate the energy intensity of corn production based on the same method. Ass 34,208 Btu/bu. This is 63.41% of the estimate made in this report. Thus the seed energy intensity estimate can be considered a valid, but crude, estimate.

As a check, a rough direct estimate can be made of the energy use to grow seed. David Bruch cited some 1994 production numbers of 47 units net production per acre, and planting rates of about 27,000 plants per acre. This works out to 3 acres seeded per unit, or:

47	units seed/acre seed
3	acres grain/unit seed
141	acres grain/acre seed

Energy use p	6,503,299	Btu/acre corn

Assuming equivalent energy use per acre seed, energy use per acre grain for seed is:	46,123	Btu/acre corn
or:	383	Btu/bu corn

This is already double the estimate in reference 1, and does not include any additional energy for seed processing. There are many aspects of seed production which are markedly more energy intensive than grain. For example, seed corn is planted in two passes, one for each of the parents. An additional tractor pass is made to burn back one or two rows to ensure proper pollination. This year, for example, some fields were sprayed up to 4 times from corn borer. Seed corn is also mechanically detassled. Probably the most significant area of additional energy use, however, is in drying and storage. In some cases pesticide use is very much higher. Seed corn is harvested wet (35% moisture) and dried on the ear down to 12% moisture. Using data from Table 17 an estimate of drying energy use can be made:

Harvested moisture of c	35%	
Stored moisture of corn	12%	
Harvested water weight	26.54	lb/bu
Stored water weight	6.72	lb/bu
Stored corn weight	49.28	lb/bu
Water to be evaporated	19.82	lb/bu
Gross Energy to Dry Se	35,691	btu/bu seed
Gross Energy to Dry Se	637	btu/lb seed
Energy per unit corn pro	75.43	btu/bu corn

This does not include the water in the cob itself, so energy use for drying would be even higher. Clearly Different practices in the seed industry lead to dramatically higher energy costs. The calculation below is a rough estimate of incremental additions in energy use on the farm for hybrid seed production. Included are estimates of triple the farm machinery use, 20% additional energy for drying due to water in the cob, and double the energy use for pesticides.

Item	Energy use per Acre	Estimated Mu	Energy Use per A	Energy Use p	Energy Use per Bu corn
Nitrogen	2,876,833	1	2,876,833	55,700	118
Potash	115,234	1	115,234	2,231	5
Phosphate	197,113	1	197,113	3,816	8
Lime	90,198	1	90,198	1,746	4
Chemicals	325,118	2	650,236	12,590	27
Drying	1,606,101	1.2	1,927,322	37,316	79
Farm Vehicle	1,644,030	3	4,932,089	95,494	202
Total	6,854,628		10,789,026	208,894	442

Notes: Assumes 80,000 kernals/unit and 1,300 kernals/lb. Some additional energy is used for airconditioned storage of seed, packaging, and transportation, but it seems unlikely that this would increase the total as high as the value estimated from btu/$ GDP. The actual value is probably between 600 and 1800 btu/bu corn. Lacking more detailed data on corn seed production practices, however, the estimate based on btu/$ will be used.

Table 12 Energy Use in Lime and Sulfur Production

(1) Hudson, Charles L. 1982. Energy Requirements for Materials Used in Vehicles Characterized for the Tapcut Project, Argonne National Laboratory, ANL/EES-TM-211.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

(4) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(5) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(6) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

Energy Use in Lime and Sulfur Production

Lime	316 kcal/kg	(3)	569 Btu/lb	
	566 Btu/lb	(4)	566 Btu/lb	
	315.45 kcal/kg	(2)	568 Btu/lb	This source explicitly states that 300 kcal/kg is transport.
		Average	568 Btu/lb	
		St. Dev.	1 Btu/lb	

Notes: I suspect that all three of these sources are relying on the 1980 estimate by Pimentel of the energy use to produce limestone. Pimentel's estimates suggest that almost all of the energy use is for transport of the limestone, while mining costs are very small. He cites no data source for the transportation estimate, however, making the total value somewhat questionable. Apparently this single value has progagated through the literature for some time. There is no apparent source of better data. The mining part of the energy consumption estimate is based on 1972 Census of Mineral Industries data.

	GJ/mt		
Sulfur	7.38	9,511 Btu/lb	(5)
Percent of Su	21%	1997 Btu/lb	(6)

Notes: About 15% of domestic sulfur use in the U.S. is domestically produced, Frasch Process sulfur. Domestically produced recovered sulfur accouts for 55%. Since sulfur recovery is often carried out in the purification of fuel feedstocks, or for pollution control purposes, it is unclear whether energy use in these processes should be counted towards sulfur production. Hudson (1) cites an energy intensity of sulfur production of 443 Btu/lb.

Table 13 Fertilizer Type Mix in Iowa (a state heavily devoted to corn production)

(1) Tennessee Valley Authority, Commercial Fertilizers: 1994, TVA Environmental Research Center, TVA, Muscle Shoals, Alabama.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Iowa Fertilizer Consumption :1994 (1)

		Raw Input Quanitity	Units	Notes:	Percent	
Nitrogen	Multi Nutrient Grade	103186	short tons N	p. 17		
	Single Nutrient Grade	932724	short tons N	p. 17		
	Total N	1035910	short tons N	p. 17		
Phosphates	Multi Nutrient Grade	284130	short tons P2O5	p. 17		
	Single Nutrient Grade	9844	short tons P2O5	p. 17		
	Total P2O5	293974	short tons P2O5	p. 17		
Potassium	Multi Nutrient Grade	38507	short tons K2O	p. 17		
	Single Nutrient Grade	403517	short tons K2O	p. 17		
	Total K2O	442024	short tons K2O	p. 17		
Single Nutrie	Anhydrous Ammonia	597445	short tons N	p. 20	65.08%	
	Nitrogen Solutions	235127	short tons N	p. 20	25.61%	
	Urea	85472	short tons N	p. 20	9.31%	
	Total Single	918044	short tons N		98.43%	Of total single nutrient N
Multiple Nutr DAP		378850	short tons DAP	p. 15		

		68193	short tons N	p. 15	66.09% Of total multi nutrient N
		174271	short tons P2O5	p. 15	59.28% Of total P2O5
Potassium	Potassium Chloride	400,923	short tons K2O	p. 21	90.70% Of total K2O

Notes: Fertilizer use in Iowa is weighted towards single nutrient types except for phosphates, for which DAP is the most common type used.
In order to simplify the evaluation of energy and emissions associated with fertilizer manufacture, nitrogen energy intensity will be estimated from the weighted average of the single nutrient nitrogen sources, and phosphate energy intensity will be taken from a generic value for phosphate fertilizers. Emissions estimates will then be derived from the quantity of raw materials and intermediates used to manufacture the fertilizers.

Physical and Chemical Characteristics of Nitrogen Solution (2)
(28% N in solution)

Urea N: Amm	1.04 (unitless)
Urea N	50.98%
Ammonium N	49.02%

Table 14 Corn Production Energy Use for Fertilizer

Fertilizer Energy Intensity in Corn Production

		Quantity (lb/bu)	Fuel Energy Inter (Btu/lb)	El. Energy In (kwh/lb)	Fuel Energy Intens (Btu/bu)	Electric Energy Inten (kwh/bu)	Notes:	N.G	Fuel Oil	Electricity	Total Fuel	Total
Calculated	N	1.03	22,295	0.097	22,871	0.100	Fraction of Fertilizer type and fraction of makeup of nitrogen solution from T	22,871	0	0.100		23,866
	P	0.39	2,213	0.196	867	0.077	Average of fertilizer types	425	442	0.077		1,635
	K	0.46	1,156	0.091	536	0.042	Average value	536	0	0.042		956
	Total	1.88	25,663	0.384	24,273	0.722		23,831	442	0.218	24,273	26,458

Notes: Energy use from fertilizer consumption is calculated from the quantity of fertilizer used (Table 2), the energy intensity of fertilizer production (Table 7), and, for nitrogen, some information about the mix of nitrogen fertilizer types used in Iowa (Table 13). Fuel mix information is also in Table 7.

Table 15 Direct Energy Use in Corn Production

(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(2) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

Fuel Use by State (1)

	Units	Illinois	Indiana	Iowa	Michigan	Minnesota	Nebraska	Ohio	South Dakota	Wisconsin	Weighted Average
Diesel	Btu/bu	4793	5843	4686	8620	5427	18881	5131	10650	9184	7713
Gasoline	Btu/bu	3439	3710	3281	3530	3019	4301	2723	4846	2802	3493
LP Gas	Btu/bu	1515	1619	3292	2654	3287	2510	2780	5705	1578	2575
Natural Gas	Btu/bu	479	85	0	464	0	12632	85	0	90	2058
Electricity (2)	kwh/bu	0.097	0.235	0.041	0.097	0.233	0.744	0.081	1.094	0.605	0.276
Custom Work	Btu/bu	1480	1213	1289	927	1131	1106	981	1271	3619	1371
Custom Dryin	Btu/bu	902	1153	1463	1654	1321	1153	764	39	964	1134
Input Hauling	Btu/bu	1062	1062	1062	1062	1062	1062	1062	1062	1062	1062

Total

Diesel	Btu/bu	10,146
Gasoline	Btu/bu	3,493

LP Gas	Btu/bu	3,210
Natural Gas	Btu/bu	2,557
Electricity (2)	Kwh/bu	0.276
Total		19,406

Notes: Electricity use per bushel has been converted back to Kwh using the conversion factor given in reference 1 (12,456 btu/kwh). This value can be checked in reference 2, and is correct. Following the convention in reference 1, energy use for custom work and input hauling has been allocated to the diesel category. Energy use in custom drying is allocated to the LPG and natural gas categories according the the relative importance of these two fuels (44% N.G.: 56% LPG).

Table 16 Dryer Type Specific Energy Intensity Estimates

(1) Personal Communication with Dr. Charles Hurburgh, Iowa State University, July 24, 1995.

(2) Personal Communication with Dr. Fred Bakker-Arkema, Michigan State University, Department of Ag. Engineering, July 27, 1995.

(3) Personal Communication with Bill Wilcke, University of Minnesota, Department of Ag. Engineering, July 25, 1995

(4) Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

Corn Drying Energy Consumption Estimates

Dryer Type	Energy	Units	Source	Notes:
Low Temp.	1,400	Btu/lb water	(1)	He gave these as the range of possible values, in
High Temp.	3,000	Btu/lb water	(1)	which most dryers should fall.
Ambient Air-L	1,450	Btu/lb water	(2)	Range: 1,200 to 1,600
High Temp. B	1,950	Btu/lb water	(2)	Range: 1,500 to 2,400
Continuous High Temp.				
Cross Flow	2,050	Btu/lb water	(2)	Range: 1,700 to 2,400
Mixed Flow	1,800	Btu/lb water	(2)	Range: 1,600 to 2,000
Concurrent F	1,650	Btu/lb water	(2)	Range: 1,500 to 1,800
Average	1,833	Btu/lb water		
Bin Batch	1,500	Btu/lb water	(3)	
Column Batc	2,100	Btu/lb water	(3)	
Continuous F	2,650	Btu/lb water	(3)	Range: 2,100 to 3,200
Natural w/ele	1	kwh/bu	(3)	From 22 to 15% moisture
	870	Btu/lb water		

Percent of Corn Dried By Type: Iowa 1990 (4)

		Energy Inten	Product
Column Type	9.1%	2,100	191
Column Type	13.6%	1,833	249
Batch-in-Bin	21.4%	1,500	321
Continuous-f	17.5%	2,650	464
Bin Dryer wit	35.9%	1,500	539
Other	2.5%	1,500	38

Mid-Range Energy Intensity Estimate
1,801 Btu/lb water

Table 17 Net Corn Drying Energy Intensity

(1) Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

(2) Hill, L.D., J.P. Brophy, S. Zhang, and W. Florkowski. 1991. Farmer Attitudes Towards Technological Changes Affecting Grain Handling and Quality, Bulletin 805, University of Illinois at Urbana-Champaign, College of Agriculture, Agricultural Experiment Station.

(3) CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

(4) Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

(5) Personal communication with Bill Wilcke, University of Minnesota, Department of Agricultural Engineering, July 25, 1995.

(6) Personal communication with Fred Bakker-Arkema, Michigan State University, July 27, 1995.

(7) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(8) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

Source:
Corn Dried by Method: Percent of To(1)

Year	1986	1988	1989	1990	Average
Natural Dryin	15.3	20.7	22.8	19	19.45
On Farm Arti	68.1	61.5	58.1	62.1	62.45
Off Farm Arti	16.6	17.8	19.1	18.9	18.10%

Source:
Percent of Cc(2)

Source:
(8)

	1971	1976	1986	1991
Illinois	34	42	49	38
Iowa	27	45	53	47
Indiana	36	53	58	31
Average	32	47	53	39

Notes: Information on corn drying varies significantly from source to source. The above information includes some of the available estimates of the fraction of corn dried, and the fraction dried on and off of the farm. Because of conflicting estimates, estimates of fuel use for corn drying were taken directly from reference 7. This are compared below to theoretical values.

Item	Value	Units	Source	Notes:
Specific Heat of Water	1	btu/lb-degree Ra	(4)	
Enthalpy of vaporization	970.30	btu/lb	(3)	At 1 atmosphere
Energy to vaporize water from 70 F	1112.30	btu/lb	(3)	
Harvested moisture of corn	23%		(5)	
Stored moisture of corn	15%		(5)	
Harvested water weight	14.22	lb/bu		
Stored water weight	8.40	lb/bu		
Stored corn weight	47.60	lb/bu		
Water to be evaporated	5.82	lb/bu		
Gross Energy to Dry Corn	10,480	lb/bu		
Net Energy to Dry Corn	5,764	lb/bu		

Notes: Assuming an average of 55% of corn is dried, net energy use values correspond to estimates in reference 7 for corn dried from 23% to 15%, or 8% points. This estimate is not inconsistent with rough estimates

given by Bill Wilcke (10%) and Fred Bakker-Arkema (5% to 12%). Because more accurate data are lacking, it will be assumed that the energy intensity value derived in reference 7 is the most appropriate. Thus all energy use for drying is accounted for in Table 15.

Table 18 Net On-Farm Energy Use

From Table 15

Energy Use for Corn, 9-State Weight	Raw/ Input Quan.	Raw/ Input Units	Source	Transformed Input Quan.	Transformed Input Units	Notes
Diesel	10,146	Btu/bushel	Table 15	10,146	Btu/bu	Based on 9 state average.
Gasoline	3,493	Btu/bushel	Table 15	3,493	Btu/bu	Based on 9 state average.
L.P.G	3,210	Btu/bushel	Table 15	3,210	Btu/bu	Based on 9 state average.
Natural Gas	2,557	Btu/bushel	Table 15	2,557	Btu/bu	Based on 9 state average.
Electricity	3,438	Btu/bushel	Table 15	0.276	Kwh/bu	Based on 9 state average.
Total	22,166	Btu/bushel				

Table 19 Energy Use for Fertilizer in Corn Production

Calculated Values from the last rows of Table 14

Energy Use for Fertilizer Production	Raw/Input Quantity	Units	Source	DQI	Notes:
Electricity	0.218	Kwh/bushel	Table 14	7	
Fuel Oil	442	Btu/bushel	Table 14	7	
N.G.	23,831	Btu/bushel	Table 14	7	
Total	26,458	Btu/bushel	Table 14	7	

Table 20 Energy Use for Pesticide Use in Corn Production

From Tables 9 and 10.

Pesticide Pro Units	Quantity (lb/bu)	Energy Inten (Btu/lb)	Energy Use (Btu/bu)	Oil (Btu)	Gas (Btu)	Coal (Btu)
Herbicides	0.023	97,575	2,234	1,080	722	432
Insecticides	0.0022	101,742	225	106	76	44
Pesticide For and Packagin	Quantity (lb/bu)					
Herbicides	0.023	9,451	216	105	70	42
Insecticides	0.0022	9,451	21	10	7	4

Total Pesticide Energy Use

Oil	1,300	Btu/bu
N.G.	875	Btu/bu
Coal	522	Btu/bu
Total	2,697	Btu/bu

Notes: Energy intensity for production from Table 9, reference 1. Energy intensity for formulation and packaging from Table 10, reference 2. Fuel mix for total energy use from Table 10, reference 1.

Table 21 Energy Use for Seed in Corn Production

(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

Fuel	% fuel	Energy	Units
Gasoline	6.80%	128	Btu/bu
N.G.	59.90%	1,128	Btu/bu
Diesel	26.50%	499	Btu/bu
Oil	6.80%	128	Btu/bu
Seed Produc	100.00%	1,883	Btu/bu

Notes: Energy type splits from reference 1, in percent, applied to total energy for seed production from Table 11.

Table 22 Energy Use for Lime and Sulfur in Corn Production

From Table 6

Lime	728	btu/bu
Sulfur	20.39	btu/bu
Total	748	btu/bu

Energy Split

Diesel	748	btu/bu

Note: Reference (1) gives an energy type distribution for lime that includes mostly natural gas and coal. Reference (2) suggests that 95% of fuel use in limestone production is for transportation. Since reference (2) is more explicit about the processes uses, it is assumed that 300 kcal/kg of energy use is for truck haulage, and that diesel trucks are used for this haulage. The remaining energy consumption, and the consumption of energy for sulfur, are lumped into the diesel category because they are small contributions, and there is little data about the mix of fuels for these categories.

Table 23 Total Energy Use in Corn Production

Sum of Previ Total		Units	Table 12 Pesticide Produc	Table 13 Direct Use	Table 14 Fertilizer Prod	Table 15 Seed Produc	Table 16 Limestone/Sulfur
N.G.	28,391	Btu/bushel	875	2,557	23,831	1,128	0
Diesel	11,393	Btu/bushel	0	10,146	0	499	748
LPG	3,210	Btu/bushel	0	3,210	0	0	0
Coal	522	Btu/bushel	522	0	0	0	0
Oil	1,870	Btu/bushel	1,300	0	442	128	0
Gasoline	3,621	Btu/bushel	0	3,493	0	128	0
Electricity	0.494	Kwh/bushel	0.000	0.276	0.218	0.000	0.000
Total Fuel	49,007	Btu/bushel	2,697	19,406	24,273	1,883	748
Total Electric	0.494	Kwh/bushel	0.000	0.276	0.218	0.000	0.000
Grand Total	53,952	Btu/bushel	2,697	22,166	26,458	1,883	748

Table 24 Nitrogen Oxide Emissions from Corn Production

(1) Eichner, Melissa. 1990. Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data, J. of Environmental Quality, 19:272-280(1990)

(2) Anderson, I.C., and J. S. Levine. 1987. Simultaneous Field Measurements of Biogenic Emissions of Nitric Oxide and Nitrous Oxide,

Journal of Geophyical Research, vol. 92, no. D1, pp. 965-976, January, 1987.

(3) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

(4) Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

(5) Watson, R.T. et al. 1990. Greenhouse Gases and Aerosols, in Intergovernmental Panel on Climate Change, Climate Change: The IPCC Scientific Assessment Report Prepared by Working Group I, J.T. Houghton, et al (ed.), UK, 1990.

LCI Component		Raw Input Quantity	Units	Source	Tranformed Input Quantity	Units	Notes
N2O Emissions							
		0.01	percent	(4)	1.03E-04	lb/bu	Refs 4 and 5 probably are citing the same data, though they reference different sources.
		2	percent	(4)	2.05E-02	lb/bu	
		0.01	percent	(5)	1.03E-04	lb/bu	Refs 4 and 5 probably are citing the same data, though they reference different sources.
		2	percent	(5)	2.05E-02	lb/bu	
	Anhydrous Ammonium	2.7	percent	(1)	2.77E-02	lb/bu	Evaluated results of 104 field experiments
	Ammonium Nitrate	0.44	percent	(1)	4.51E-03	lb/bu	
	Ammonium Chloride or	0.25	percent	(1)	2.56E-03	lb/bu	
	Urea	0.11	percent	(1)	1.13E-03	lb/bu	
	Calcium Nitrate	0.07	percent	(1)	7.18E-04	lb/bu	
		1.2	percent	(2)	1.23E-02	lb/bu	
	Corn	1.5	percent	(3)	1.54E-02	lb/bu	Cites Mosier, A. R. et al. 1986. Soil Losses of Dinitrogen and Nitrous Oxide from Irrigated Crops in Northeastern Colorado, Soil Science Society of America Journal, 50:344-348
	Corn (Anhydrous Ammo	1.29	percent	(1)	1.32E-02	lb/bu	This data is specific to corn and anhydrous ammonium, so it will be used here.
NO Emission		0.79	percent	(2)	8.10E-03	lb/bu	

Notes: NO2 emissions vary by fertilizer type and crop. Reference 1 gives a value for anhydrous ammonia fertilized corn. Since this data most closely represents average practices, and since the value is consistent with other results, it is used in the inventory.

Table 25 Pesticide and Nutrient Loss to Surface and Groundwater

(1) Glotfelty, D.E., et al. 1984. Atrazine and Simazine Movement to the Wye River Estuary, Journal of Environmental Quality, 13:115-121

(2) Bowman, B.T., et al. 1994. Tranport of Herbicides and Nutrients in Surface Runoff from Corn Cropland in Southern Ontario Canadian Journal of Soil Science, 7491):59-66, 1994

(3) Buhler, D.D., et al. 1993. Water Quality: Atrazine and Alachlor Losses from Subsurface Tile Drainage of a Clay Loam Soil, Journal of Environmental Quality, 22:583-588, 1993

(4) Battaglin, W.A., D.A. Goolsby, and D.K. Mueller. 1994. Relations Between Use, Concentration, and Transport of Agricultural Chemicals in the Mississippi River Basin, in Proceedings of the Annual Summer Symposium of the American Water Resource Association, Effects of Human Induced Changes on Hydrologic Systems, June 26-29, 1994, Jackson Hole, Wyoming.

(5) Goolsby, D.A., E.M. Thurman, M.L. Pomes, and W.A. Battaglin. 199. Temporal and Geographic Distribution of Herbicides in Precipitation in the Midwest and Northeast United States, 1990-1991, in Proceedings of the Fourth National Conference on Pesticides, New Directions in Pesticide Research, Development and Policy, November 1-3, 1993, Blacksburg, Virginia.

(6) United States Geological Survey. 1993. Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States, U.S.G.S. Open-File Report 93-418, U.S. G.S. , Denver, CO.

(7) The Fertilizer Institute. 1982. The Fertilizer Handbook

Pesticides are transported from the point of application by several methods: surface runoff, leaching, volatilization, and direct airborne dispersal of pesticide which does not reach the target. These pesticides can be detected in surface water, groundwater, and rainwater. References 5 and 6 give information on the prevalance of pesticides in rainwater samples in the midwest. Detection of pesticides and pesticide metabolites is common, and concentrations may reach as high as Federal limits on drinking water concentrations. The total quantity of pesticides found in rainwater is small relative to applications (less than 1%) and does not account for total air emissions of pesticides. It is suggested in these studies that degradation, dry deposition, and drift outside of the study area may account for the remaining air emissions of pesticides. These air emissions have been quantified in Table 42. It should be noted that air emissions of pesticides which appear in rainfall also serve as a pesticide load on surface water.

Pesticides also appear in near surface aquifers. The concentrations found in groundwater are generally much smaller than surface water concentrations. No data has been identified which tracks aquifer loading as a fraction of total pesticide use in a particular region. Because this value is probably small relative to surface water loads, it will be treated as negligible. The data below thus give a gross quantification of pesticide flux to water systems in the midwest.

LCI Component		Raw Input Quantity	Units	Source	Notes
Herbicides	Atrazine	2.50%	Percent	(1)	Midrange loss of atrazine for years in which significant rainfall occurred within two weeks of application
		0%	Percent	(2)	
		6%	Percent	(2)	Up to this level when rain immediately follows application
		1.53%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
	Melachlor	0%	Percent	(2)	Up to this level when rain immediately follows application
		4%	Percent	(2)	
		0.79%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
	Alachlor	0.22%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
	Cyanazine	1.66%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
	Nitrates	15.32%	Percent	(4)	Annual average based on Mississippi Basin loadings and associated use levels.
	Phosphorous	1.00%	Percent	(7)	Rough estimate given as less than 1%
	Potassium	3.50%	Percent	(7)	Rough estimate given as midway between N (6%) and P (1%)
Subsurface lo	Alachlor	0.10%	Percent	(3)	Subsurface loss only
	Atrazine	0.10%	Percent	(3)	

Application rates for insecticides are similar to those for herbicides (generally on the order of 1 lb/acre) but the fraction of acreage treated is much smaller (8% for chlorpyrifos and terbufos compared to 69% for atrazine). This may to some degree explain the lower frequency of detections of insecticides. Reference 6 includes results from samples taken on 8 river systems with the most frequently detected of the top three corn insecticides, fonofos, occurring in a maximum of 34 percent of samples (Illinois River). By comparison virtually all samples from all rivers had detectable quantities of atrazine and metolachlor. Other insecticides, such as diazinon and carbofuran were more prevalent. Because detailed estimates of the fraction of insecticides entering surface water systems have not been made, a rough approximation of 1% will be used.

Table 26 PM-10 Fugitive Emissions from Corn Production

(1) AP-42 Compilation of Air Pollutant Emission Factors, 5th Edition Chapter 9.3.2, Grain Harvesting.

(2) U.S. Environmental Protection Agency. 1994. National Air Pollutant Emission Trends, Office of Air Quality, EPA-454/R-94-027.

(3) United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

(4) United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

Year 1993 Source	Raw Input Quantity 1993	Raw Input Quantity 1987	Units		Notes
Fugitive PM- (2) from Agricultural Cropland	6,842	7,338	thousand short tons		
Cultivated No(4)	325,462	350,908	thousand acres		As a check on this number, area planted in 1993 can be taken from reference (3). This totals 259,404 thousand acres, but excludes hay production, for which harvested area is given. Adding hay harvested area gives rough estimate of total planted area of 319,029 thousand acres, similar to the NRI value.
PM-10 Emiss(calculated)	0.0210	0.0209	short tons/acre		
PM-10 Emiss(calculated)	42.045	41.823	lb/acre		
Average value		41.93	lb/acre	0.348	lb/bu

Notes: Reference (2) uses methods described in method (1) to estimate fugitive dust emissions. These can be highly variable dependent on weather conditions. Because reference (4) only gives estimates in 5 year intervals, only two years worth of values can be estimated. Other sources can be used to estimate total cropland, but it is not clear which source of data is most appropriate. The PM-10 emissions are also based on factors only for agricultural tilling. Particulate is also emitted from grain harvesting operations. Reference (1) also gives emission factors for these operations for sorghum. The calculation below shows that these emissions are negligible with respect to the values estimated above. The emission rate is a general factor for cropland, but lacking additional data is used as a surrogate for emissions from corn cropland.

Sorghum Harvesting Emissions (reference 1, Table 9.3.2)

Item	Value	Units	Value	Units
Emission Rate				
Harvest Mac	6.5	lb/sq mile	0.01016	lb/acre
Truck Loadin	0.13	lb/sq mile	0.00020	lb/acre
Field Transpo	1.2	lb/sq mile	0.00188	lb/acre
Total	7.83	lb/sq mile	0.01223	lb/acre

Table 27 Emissions from Energy Consumption in Nitrogenous Fertilizer Manufacture

(1) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(2) United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

(3) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

(4) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Energy for Nonfuel Purposes (MECS Nitrogenous Fertilizers	Raw Input Quantity	Units	Transformed Input Quantity	Units	Notes:
Natural Gas	289	Tbtu	52.07%	Feedstock Share	

Total	290	Tbtu

Energy for Heat, Power, etc. (MECS Table A4)

Natural Gas	266 Tbtu	47.93%	Fuel Share
Electricity	10 Tbtu		
Other	4 Tbtu		

Total Primary Energy Consumption (MECS Table A1)

Natural Gas	555	Tbtu
Electricity	10	Tbtu
Other	568	Tbtu

Large Industrial Boiler Emission Factors (AP-42, Tables 1.4-1 to 1.4-3)

SO2		0.6	lb/million cubic ft	0.00058	lb/million btu	
NOx	Uncontrolled	550	lb/million cubic ft	0.53295	lb/million btu	
	Controlled-Lo NOx	81	lb/million cubic ft	0.07849	lb/million btu	
	Controlled-FGR	53	lb/million cubic ft	0.05136	lb/million btu	
	Average Controlled	67	lb/million cubic ft	0.06492	lb/million btu	
	Average	308.5	lb/million cubic ft	0.29893	lb/million btu	
CO		40	lb/million cubic ft	0.03876	lb/million btu	
PM-10		13.7	lb/million cubic ft	0.01328	lb/million btu	This factor is given as the sum of filterable and condensible particulate. All PM emissions from N.G. consumption are thought to be < 10 microns in diameter
Methane		0.289	lb/million cubic ft	0.00028	lb/million btu	
Non-methane VOC's		1.41	lb/million cubic ft	0.00137	lb/million btu	
CO2		14.47	million metric ton	116.9	lb/million btu	

Heat Content of Natural Gas (AER, T	1,032	Btu/cubic foot

Emissions from the Use of N.G. in the Manufacture of Fertilizer per Unit Corn Production

SO2	6.37E-06	lb/bu
NOx	3.28E-03	lb/bu
CO	4.25E-04	lb/bu
PM-10	1.46E-04	lb/bu
Methane	3.07E-06	lb/bu
Non-methane VOC's	1.50E-05	lb/bu
CO2	1.28	lb/bu

Notes: The share of N.G. used as feedstock for nitrogenous fertilizer manufacture vs. fuel is used to reduce emissions estimates to account for N.G. not consumed in boilers.
Emission factors are converted into units of lb/million btu, which are multiplied by energy consumption and share of energy used as fuel.
Emissions from the consumption of electricity by the industry will be calculated by the electricity module.

N.G. is used as a feedstock through a reforming process to produce hydrogen gas. This is the predominate process for ammonia production in the U.S.
The hydrogen is reacted with nitrogen to form ammonia. This process results in the production of carbon dioxide and carbon monoxide. Carbon monoxide can be converted back to carbon dioxide through the water-gas shift reaction. Carbon dioxide has industrial use in several areas including the manufacture of urea from ammonia, but some carbon dioxide is emitted from the process. These and other process related emissions are treated in Table 35.

Table 28 Emissions from Diesel Consumption in Limestone Production and Farm Input Hauling

(1) Boynton, Robert S. 1980. Chemistry and Technology of Lime and Limestone, Second Edition, John Wiley and Sons, Inc., New York.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

(4) USDA. 1995.

(5) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(6) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Reference (2) suggests that of 315.45 kcal/kg energy input to limestone production, 300 kcal/kg is for trantportation of the limestone to the user. Reference (4) on the other hand lists fuel type for lime split between natural gas, diesel, and coal, suggesting that transporation is not the major area for energy consumption. Reference (5) also explicitly states that energy use estimates for lime production include energy for mining, production, transporation, storage, and transfer. Because reference (2) is most explicit about energy use, emissions from the production of lime will be estimated based on truck emission factors for diesel trucks. It is also assumed that diesel fuel use by the phosphatic and potassium fertilizer industries is also consumed in trucks.

Vehicle Capa	Raw Input Quantity	Units	Source	Tranformed Q	Units
Light Diesel T	10,000	lb	BMI Transport Model		
Heavy Diese	42,000	lb	BMI Transport Model		

Vehicle Usage Rates				Notes:
Light Diesel T	50.00%	percent	(3)	My guess based on zero data
Heavy Diese	50.00%	percent	(3)	

Mileages			
Short Haul D	7.10	Miles/gallon	BMI Transport Model
Long Haul Di	5.30	Miles/gallon	BMI Transport Model

Diesel Energ	5.825	Million Btu/ba	(6)

Vehicle Registration Mix: January 1 & emissions factors , g/mile

	Gas Trucks				Light Duty Diesel				Heavy Diesel Trucks				Product of we
Model Year	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Model Year
Model Year -	0	2.8	12.6	4.4	0.008	0.3	1.2	0.9	0.031	2.4	7.9	11	Model Year -1
Model Year -	0.136	2.9	13.2	4.5	0.006	0.3	1.2	0.9	0.007	2.5	8.3	11.1	Model Year -
Model Year -	0.116	3.1	14.6	4.8	0.008	0.4	1.2	0.9	0.008	2.6	9.1	11.5	Model Year -
Model Year -	0.099	3.2	15.6	4.9	0.011	0.4	1.3	1	0.01	2.7	9.9	12	Model Year -
Model Year -	0.085	3.4	16.5	5.1	0.017	0.4	1.3	1	0.012	2.8	10.5	12.2	Model Year -
Model Year -	0.072	3.6	17.7	5.4	0.023	0.5	1.4	1	0.014	2.9	11.1	12.5	Model Year -
Model Year -	0.062	3.7	18.4	5.5	0.029	0.5	1.4	1.1	0.017	3	11.6	12.7	Model Year -
Model Year -	0.053	3.8	19.1	5.6	0.035	0.5	1.4	1.1	0.021	3.1	12.1	12.9	Model Year -
Model Year -	0.045	3.9	19.7	5.7	0.041	0.5	1.5	1.1	0.025	3.2	12.5	13.1	Model Year -
Model Year -	0.038	4.8	41.6	5.2	0.047	0.6	1.5	1.1	0.03	3.3	13.2	17.9	Model Year -
Model Year -	0.033	5.2	50.2	5.2	0.053	0.6	1.5	1.2	0.036	4	13.7	18.2	Model Year -
Model Year -	0.028	12.8	158.20	5.6	0.059	0.6	1.6	1.6	0.043	5.6	14.8	18.9	Model Year -
Model Year -	0.024	13	160.40	5.6	0.065	0.6	1.6	1.6	0.051	5.7	15.1	18.9	Model Year -
Model Year -	0.02	13.1	165.20	5.7	0.071	0.6	1.6	1.7	0.061	5.8	15.4	18.9	Model Year -
Model Year -	0.018	13.2	167.80	5.7	0.077	0.7	1.7	1.7	0.073	6.7	16.9	20.5	Model Year -
Model Year -	0.015	13.8	182.5	6.1	0.083	0.7	1.7	1.9	0.088	6.8	17.2	20.5	Model Year -
Model Year -	0.013	13.9	184.80	6.1	0.089	1.4	2.4	1.9	0.105	7.3	20.2	24.8	Model Year -
Model Year -	0.011	18.3	211.10	6.4	0.095	1.4	2.5	2	0.126	7.4	20.5	24.8	Model Year -
Model Year -	0.009	19.8	241.30	7.3	0.101	1.5	2.5	2	0.151	7.5	20.7	24.8	Model Year -
Model Year -	0.045	19.9	243.30	7.4	0.027	1.5	2.5	2	0	7.5	20.9	24.8	Model Year -
Weighted Av	92.20%	5.9	53.3	5.3	94.50%	0.5	1.4	1.1	90.90%	3.7	12.1	14.6	sum

Emission Factors Raw Input Qu Units

Short Haul D	Hydrocarbons	0.5	g/mile
	Carbon Monoxide	1.4	g/mile
	NOx	1.1	g/mile
Long Haul Di	Hydrocarbons	3.7	g/mile
	Carbon Monoxide	12.1	g/mile
	NOx	14.6	g/mile
Emissions			
	Hydrocarbons	0.00043	lb/bu
	Carbon Monoxide	0.00138	lb/bu
	NOx	0.00161	lb/bu
	CO2	0.29174	lb/bu

Table 29 Emissions from Farm Equipment

(1) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Report, EPA 460/3-91-02.

(2) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

(3) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(4) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

Farm Equipm	Units	Raw Input Quantity						Source	Notes
		HC	CO	NOx	SOx	Particulate	Aldehydes		
Diesel Tracto	lb/1000 gallons	63.55	175	438.59	31.2	45.7	12	(2)	Weighted by factors for large 2WD, small 2WD, and 4WD tractors.
Diesel Non-T	lb/1000 gallons	72.52	171	435	5.28	51.3	10.2	(2)	Diesel HC values include exhaust and crankcase emissions.
Gasoline Tra	lb/1000 gallons	178.85	4,456	213.232	5.31	8	6.8	(2)	Gasoline HC values include exhaust, crankcase,
Gasoline Nor	lb/1000 gallons	192.15	4,456	213.232	5.28	6.86	4.1	(2)	and refueling emissions.

Carbon Dioxide Emission Factors

	Raw Input Quantity	Units	Source	Transformed	Units	Transformed	Units
Diesel	19.95	Million mtons	(4)	43.98	lb C/million bt	161.16	lb CO2/million btu
Gasoline	19.41	Million mtons	(4)	42.79	lb C/million bt	156.79	lb CO2/million btu

Energy Value	Raw Input Quantity	Units	Source	Transformed	Units
Diesel	5.825	Million Btu/ba	(3)	138,690	Btu/gallon
Motor Gasoli	5.253	Million Btu/ba	(3)	125,071	Btu/gallon

Direct On-Fa	Raw Input Quantity	Units	Source	Transformed	Units
Diesel	9,583	Btu/bu	Tables 13 and 15	0.069	Gallons/bu
Motor Gasoli	3,621	Btu/bu	Tables 13 and 15	0.029	Gallons/bu

Emissions fro	Quantity	Units
HC	9.57E-03	lb/bu
CO	1.41E-01	lb/bu
NOx	3.65E-02	lb/bu

SOx	2.31E-03	lb/bu
Particulate	3.74E-03	lb/bu
Aldehydes	4.70E-04	lb/bu
CO2	2.11	lb/bu

Notes: Reference (2) lists percentage energy output estimates for diesel equipment. According to that data about 85% of energy use is by tractors. Since non-tractor equipment includes many categories that would not be used on corn farms, such as cotton pickers, orchard sprayers, and mowers, the percentage of energy use for non-tractors on corn farms would be quite small. Also, the difference between tractor and non-tractor emission factors is small. For this reason, emissions estimates are based on the weighted factors for tractors.

Diesel energy use in tractors is taken from Table . Because the total value in this table includes diesel use in input hauling, which is accounted for in a separate table, the individual components for on farm use must be pulled out of the table separately. Diesel use to produce seed is also included in these calculations.

Table 30 Emissions from Natural Gas and LPG Use for Corn and Seed Production

(1) U.S. EPA, AP-42, Sections 1.4 and 1.5.

(2) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

Natural gas and LPG are used in corn farming for drying the corn to acceptable moisture content levels for storage, usually 12 to 13%. The EPA publishes particulate emission factors for feed dryers, but does not include emission factors for the products of combustion. In order to estimate emissions from the consumption of natural gas and LPG, factors for uncontrolled commercial boilers will be applied to the direct use of natural gas and LPG on farms, and to the use of natural gas in seed production.

Emission Factors - Natural Gas	Raw Input	Units	Source	Transformed I	Units
NOx	100	lb/million cubic fe	(1)	9.69E-02	lb/million btu
SOx	0.6	lb/million cubic fe	(1)	5.81E-04	lb/million btu
PM-10	12	lb/million cubic fe	(1)	1.16E-02	lb/million btu
CO	21	lb/million cubic fe	(1)	2.03E-02	lb/million btu
CO2	14.47	million metric ton	(2)	116.89	lb/million btu
Non-Methane VOC's	3.83	lb/million cubic fe	(1)	3.71E-03	lb/million btu
Methane	1.97	lb/million cubic fe	(1)	1.91E-03	lb/million btu

Natural Gas Use In Corn Farming an	3,685	Btu/bu	From Tables 13 and 15

Emissions

NOx	3.57E-04	lb/bu
SOx	2.14E-06	lb/bu
PM-10	4.28E-05	lb/bu
CO	7.50E-05	lb/bu
CO2	4.31E-01	lb/bu
Non-Methane VOC's	1.37E-05	lb/bu
Methane	7.04E-06	lb/bu

Emission Factors -LPG	Raw Input	Units	Source	Transformed I	Units
NOx	14	lb/million cubic fe	(1)	1.36E-02	lb/million btu
SOx	0.018	lb/million cubic fe	(1)	1.74E-05	lb/million btu
Particulate	0.4	lb/million cubic fe	(1)	3.88E-04	lb/million btu
CO	1.9	lb/million cubic fe	(1)	1.84E-03	lb/million btu
CO2	17.16	million metric ton	(2)	138.62	lb/million btu
Organic Compounds	3.83	lb/million cubic fe	(1)	3.71E-03	lb/million btu

LPG Use In Corn Farming and Seed	3,210	Btu/bu	From Tables 13 and 15

Emissions

NOx	4.35E-05	lb/bu
SOx	5.60E-08	lb/bu
Particulate	1.24E-06	lb/bu
CO	5.91E-06	lb/bu
CO2	4.45E-01	lb/bu
Organic Compounds	1.19E-05	lb/bu

Total Emissions

NOx	4.01E-04	lb/bu
SOx	2.20E-06	lb/bu
PM-10	4.28E-05	lb/bu
Particulate	1.24E-06	lb/bu
CO	8.09E-05	lb/bu
CO2	8.76E-01	lb/bu
Non-Methane VOC's	2.56E-05	lb/bu
Methane	7.04E-06	lb/bu

Table 31 Unallocated Emissions from Fuels

(1) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

In this table all fuel use for which a specific emission factor could not be found are totalled, and general emission factors used to estimate emissions. This includes fuel use for P and K fertilizer use, fuel use for pesticides and seed use of coal, and oil.

Sum of Previ Total		Units	Table 8	Table 12	Table 13	Table 14 Fertilizer Production				Table 15	Table 16
			Fertilizer Packag	Pesticide Pro	Direct Use	Nitrogen	Phosphates	Potash		Seed Product	Limestone/Sulfur
N.G.	1,836	Btu/bushel	0	875	(allocated)	(allocated)	425		536	(allocated)	0
Diesel	0	Btu/bushel	0	0	(allocated)	0	0		0	(allocated)	(allocated)
LPG	0	Btu/bushel		0	(allocated)	0	0		0	0	0
Coal	522	Btu/bushel	0	522	0	0	0		0	0	0
Oil	1,870	Btu/bushel	0	1,300	0	0	442		0	128	0
Gasoline	0	Btu/bushel	0	0	(allocated)	0	0		0	(allocated)	0
Total Fuel	4,228	Btu/bushel	0	2,697	0	0	867		536	128	0

Emission FacN.G.			Coal		Oil	
NOx	140	lb/million cub	13.7	lb/ton	20	lb/thousand gallons
SOx	0.60	lb/million cub	57	lb/ton	143.60	lb/thousand gallons
PM-10	14	lb/million cub	12.4	lb/ton	1	lb/thousand gallons
CO	35	lb/million cub	5	lb/ton	5	lb/thousand gallons
CO2	14	Million Mtons	25.58	Million Mtons	19.95	Million Mtons C/Quad
Non-Methane	2.78	lb/million cub	0.05	lb/ton	0.34	lb/thousand gallons
Methane	3.02	lb/million cub	0.06	lb/ton	0.216	lb/thousand gallons
Particulate	14	lb/million cub	17	lb/ton	2	lb/thousand gallons

Energy ValueQuantity		Units	Source	Transformed	
N.G.	1,032	Btu/cubic foo	(1)	1,032	Btu/cubic foot
Coal	22.25	million btu/to	(1)	22.25	million btu/ton

Oil	5.83 million btu/ba(1)		0.14 million btu/gallon

Emission Fac	N.G.	Coal	Oil
NOx	0.1357	0.6157	0.1442
SOx	0.0006	2.5618	1.0354
PM-10	0.0133	0.5573	0.0072
CO	0.0339	0.2247	0.0361
CO2	116.89	206.64	161.16
Non-Methane	0.0027	0.0022	0.0025
Methane	0.0029	0.0027	0.0016
Particulate	0.0133	0.7640	0.0144

Emissions in lb/bu

NOx	8.40E-04	lb/bu
SOx	3.27E-03	lb/bu
PM-10	3.29E-04	lb/bu
CO	2.47E-04	lb/bu
CO2	0.6238	lb/bu
Non-Methane	1.07E-05	lb/bu
Methane	9.68E-06	lb/bu
Particulate	4.50E-04	lb/bu

Notes: Emissions factors used for natural gas are for uncontrolled small industrial boilers. Emission factors for oil are for uncontrolled distillate oil fired commercial boilers. Emission factors for coal are for uncontrolled spreader stokers and assumes 1.5% sulfur content. The PM-10 value for coal is from AP-42 table 1.1-8 and differs slightly from the value in AP-42 table 1.1-3.

Table 32 Material resource Requirements for Fertilizer and Herbicide Manufacture

(1) The Fertilizer Institute. 1982. The Fertilizer Handbook

(2) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(3) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

Nitrogen

Nitrogenous fertilizers are primarily manufactured from ammonia, and for corn the predominant form is simply anhydrous ammonia. The most common manufacturing method for ammonia uses natural gas as a feedstock. The use of this natural gas has been accounted for in the energy consumption estimates (the nitrogen in the ammonia comes from the air).

Nitrogen solutions are the next most common N fertilizer type used in corn production. Nitrogen solutions are produced from urea and ammonium nitrate. Ammonium nitrate is again manufactured from ammonia, for which the feedstock energy use is captured in the natural gas energy consumption estimates.

Urea is produced from ammonia and carbon dioxide. Since carbon dioxide is a byproduct of steam reforming of methane (to produce ammonia) and since carbon dioxide is not typically considered a "resource", the material resource requirements for N fertilizers are entirely captured by the use of natural gas as a feedstock.

Phosphatic Fertilizers

Phosphorous is produced from calcium phosphate rock deposits found primarily in Florida and North Carolina . The production of 1 ton of P2O5 requires 3.2 tons of phosphate rock (2). On this basis the resource consumption for corn production is calculated from Table 2, or

1.25 lb/bushel

Potassium

Potassium is mined from deep potassium ore beds or recovered from natural brines such as Searles Lake, CA. The predominant source are deep mines, where potassium is recovered as KCl mixed with other salts. The quantity of KCl used to produce a unit of K20 can be calculated from the stoichiom 0.37 lb/bushel

Sulfur

Sulfur is used both as a primary nutrient in corn production, and also in the manufacture of potassium fertilizers. In fertilizer production sulfur is burned then reacted to form sulfur trioxide. The sulfur trioxide is then mixed with dilute sulfuric acid to form a concentrated solution of sulfuric acid. Finally phosphate rock is treated with sulfuric acid to produce phosp 3.06 tons
tons of sulfuric acid (H_2SO_4). The sulfuric acid reacts with phosphate rock according to the simplified reactions :
$Ca_3(PO_4)_2 + 3H_2SO_4 + 6H_2O \rightarrow 2H_3PO_4 + 3CaSO_4{*}H_2O$. The phosphorous is then burned or oxidized to phosphoric acid. According to information provided by Joyce Ober at the Bureau of Mines, one ton of DAP (the most common source of phosphates in Iowa), requires about .431 to 0.918 lb sulfur per pound of P_2O_5.

0.01 lb/bu direct application
0.43 lb/bu from phosphoric acid manufacture
0.44 lb/bu total

Sulfur is produced in the U.S. primarily from recovered sulfur at petroleum refineries, natural gas processing plants, and coking plants, which account for 55% of domestic consumption in 1993 (3). About 21% of sulfur production is through Frasch process sulfur mining
The remaining sulfur came from byproduct sulfuric acid, primary pyrites, hydrogen sulfide, and sulfur dioxide.

Table 33 Emissions of PM-10 from Crushed Stone Processing Operations

U.S. EPA, AP-42, Table 11.19.2-2.

Units are lb/ton of stone

PM-10 Emission Category	Controlled	Uncontrolled	Controlled/Uncon	Control Efficiency
Screening	8.40E-04	0.015	5.60%	94.40%
Primary Crus	-	-	-	-
Secondary C	-	-	-	-
Tertiary Crus	5.90E-04	0.0024	24.58%	75.42%
Fines Crushi	2.00E-03	0.015	13.33%	86.67%
Fines Screen	2.10E-03	0.071	2.96%	97.04%
Conveyor Tra	4.80E-05	0.0014	3.43%	96.57%
Wet Drilling:	-	8.00E-05	-	-
Truck Unload	-	1.60E-05	-	-
Truck Loadin	-	0.0001	-	-
Total (lb/ton o	5.58E-03	0.104996	-	-
Total (lb/bu c	3.58E-06	6.73E-05		

Notes: Based on this data the PM-10 emissions from stone processing are negligible with comparison to PM-10 emissions from Ag. operations in corn production (Table 26). Thus this emission is not added to total PM-10 emissions.

Table 34 Emissions from Phosphate Rock Processing

(1) U.S. EPA, AP-42, Tables 11.21-2 and 11.21-3

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Units of lb/ton of total phosphate rock feed

Emission Sou	SO2	CO2	CO	Filterable PM-10
Dryer	-	86	0.34	4.8
Calciner	-	-	-	15
Calciner With	0.0069	230	-	-

Assuming that output is roughly equivalent to feed quantity, emissions can be converted into lb/bu of corn using the relationship that 3.5 tons of phosphate rock are used to produce one ton of P_2O_5 (2).

Units of lb/bu of corn

Emission Sou	SO2	CO2	CO	Filterable PM-10
Dryer	-	0.06	2.33E-04	3.29E-03
Calciner	-	-	-	1.03E-02
Calciner With	4.73E-06	0.16	-	-
Total	4.73E-06	0.22	2.33E-04	1.36E-02

Table 35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers

U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

All units are in lb/ton of ammonia produced

Emission Sou	CO	SO2	NH3	CO2	Total Organic Compounds
Desulferizatio	13.8	0.0576			7.2
Carbon Dioxi	2		2	2,440	1.04
Condensate Steam Stripper			2.2	6.8	1.2

Since nitrogenous fertilizer use is given in terms of the nitrogen quantity, these emission factors can be converted into terms of lb/ton of nitrogen. This is done using the ratio of the molecular wt. of ammonia to the molecular wt. of nitrogen. The converted emission factors are then multiplied by the total nitrogen use, in tons.

Molecular wt	14.01
Molecular wt	1.01
Molecular wt	17.03
Ratio NH3:N	1.22

All units are in lb/ton of nitrogen produced

Emission Sou	CO	SO2	NH3	CO2	Total Organic Compounds
Desulferizatio	16.78	0.07			8.75
Carbon Dioxi	2.43		2.43	2,967	1.26
Condensate Steam Stripper			2.67	8	1.46

Finally emissions are converted to units of lb of pollutant per bushel of corn produced using the nitrogen fertilizer use rate in Table 2.

All units are in lb/bu of corn

Emission Sou	CO	SO2	NH3	CO2	Total Organic Compounds
Desulferizatio	0.0086	3.59E-05	-	-	0.0045
Carbon Dioxi	0.0012	-	0.0012	1.5217	0.0006
Condensate	-	-	0.0014	0.0042	0.0007
Total	0.0099	3.59E-05	0.0026	1.5259	0.0059

Notes: Since we know the amount of methane (and hence carbon) used as a feedstock for nitrogen fertilizer production we can calculate a bound on process related CO_2 emissions.

Feedstock M	21.78	million btu/ton ammonia
	26.48	million btu/ton N
	13,241	Btu/lb N
Carbon per u	14.47	Million metric tons C/quad
	31.90	lb C/million btu
	116.89	lb CO2/million btu
	1.55	lb CO2/lb N
	3,095	lb CO2/ton N

This shows that the CO2 emission factors for process related emissions are based on the carbon value of the feedstock, and the assumption that virtually all carbon is emitted, not used for other purposes.

Table 36 Process Emissions from Urea Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.2-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Emission Factors (lb/ton urea)

	Particulate		Ammonia	
Type of Oper	Uncontrolled	Controlled	Uncontrolled	Controlled
Solution Formation and				
Concentratio	0.021	-	18.46	-
Nonfluidized Bed Prilling				
Agricultural G	3.8	0.063	0.87	-
Fluidized Bed Prilling				
Agricultural G	6.2	0.78	2.91	-
Drum Granul	241	0.234	2.15	-
Rotary Drum	7.78	0.2	0.051	-
Bagging	0.19	-	-	-

		Source
Percentage N	46%	(2)

Emission Factors (lb/ton N)

	Particulate		Ammonia	
Type of Oper	Uncontrolled	Controlled	Uncontrolled	Controlled
Solution Formation and				
Concentratio	0.046	-	40.130	-
Nonfluidized Bed Prilling				
Agricultural G	8.261	0.137	1.891	-
Fluidized Bed Prilling				
Agricultural G	13.478	1.696	6.326	-
Drum Granul	523.913	0.509	4.674	-
Rotary Drum	16.913	0.435	0.111	-
Bagging	0.413	-	-	-

Physical and Chemical Characteristics of Nitrogen Solution
(28% N in solution)

Urea N: Amm	1.04	(unitless)
Urea N	50.98%	
Ammonium N	49.02%	

Direct Urea N	0.10	lb/bu	41.62% percent
Urea N Use R	0.13	lb/bu	58.38% percent
Total N Use f	0.23	lb/bu	

Emissions (lb/bu)

Type of Oper	Particulate Uncontrolled	Controlled	Ammonia Uncontrolled	Controlled
Solution Formation and				
Concentratio	5.24E-06	-	4.60E-03	-
Nonfluidized Bed Prilling				
Agricultural G	9.48E-04	1.57E-05	2.17E-04	-
Fluidized Bed Prilling				
Agricultural G	1.55E-03	1.95E-04	7.26E-04	-
Drum Granul	6.01E-02	5.84E-05	5.36E-04	-
Rotary Drum	1.94E-03	4.99E-05	1.27E-05	-
Bagging	4.74E-05	-	-	-
Average of P	1.25E-03	1.05E-04	4.71E-04	
Total including solution formation, and prilling	1.25E-03	#VALUE!	4.80E-03	

Notes: The only significant particulate emission source relative to other sources in corn production is uncontrolled emissions from drum granulation. By contrast controlled emissions are about 0.1% of uncontrolled emissions from this source. Furthermore, only a fraction of urea production is granular. More than 50% of urea is used in nitrogen solutions, in which case granulation is not required.
Reference (1) also states that wet scrubbers are standard equipment for drum granulators. Based on this information it is assumed that particulate emissions from urea manufacture are negligible.

Ammonia emissions are not negligible. The emission factors for ammonia in urea formation and concentration are much larger than ammonia emission factors in ammonia manufacture. The total emission factor used here is generated on the assumption that all urea passes through the concentration operation, that solid urea is produced through uncontrolled prilling operations, and the average factor for the two types of prilling operations is used. Assumptions about the granulation method have little effect on the emission factor since granulation emissions are outweighed by solution formation and concentration emissions.

Table 37 Process Emissions from Ammonium Nitrate Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.3-2.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Ammonium Nitrate is not itself an important fertilizer type in Iowa, suggesting that its use in corn production is limited. Ammonium nitrate is a constituent of nitrogen solutions, however, which are the second most common form of nitrogen application in Iowa. For this reason it is necessary to evaluate the significance of process related emissions from ammonium nitrate manufacture. These are limited to neutralizing and evaporation/concentration processes since it is not necessary to produced solid forms of ammonium nitrate for nitrogen solution manufacture.

Emission Factors (lb/ton)

Process	Particulate Controlled	Uncontrolled	Ammonia Uncontrolled	Nitric Acid Controlled	Notes
Neutralizer	4.345	0.217	18.44	1.042	Ammonia emission factor given as range from 0.86 to 36.02. Nitric acid from 0.084 to 2
Evaporation/	0.52	-	16.97	-	Ammonia emission factor given as range from 0.54 to 33.4.

Source

Ammonium N 34% (2)

Emission Factor (lb/ton N)

Process	Particulate Controlled	Uncontrolled	Ammonia Uncontrolled	Nitric Acid Controlled
Neutralizer	12.78	0.64	54.24	3.06
Evaporation/	1.53	-	49.91	-

Urea N: Amm	1.04	(unitless)
Urea N	50.98%	
Ammonium N	49.02%	

Emission Rate (lb/bu)

Process	Particulate Controlled	Uncontrolled	Ammonia Uncontrolled	Nitric Acid Controlled
Neutralizer	8.23E-04	4.11E-05	3.49E-03	1.97E-04
Evaporation/	9.85E-05	-	3.21E-03	-
Total	9.21E-04	4.11E-05	6.71E-03	1.97E-04

Notes: Particulate emissions from ammonium nitrate manufacture are negligible relative to PM-10 emissions from tilling operations. Lacking data on the use of particulate controls, these emissions will not be included in total particulate or PM-10 emissions. Ammonia emissions are significant relative to emissions of ammonia from urea and ammonia manufacturing operations. Lacking additional data the sum of the mid-range values for uncontrolled ammonia emissions and controlled nitric acid emissions are used.

Table 38 Process Emissions from Ammonium Phosphate Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.5.3-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Emission Factors (lb/ton)

Process	Particulate	Ammonia	Fluoride (as F)	SO2
Reactor/Amm	1.52	-	0.05	-
Dryer/cooler	1.5	0.02	0.04	-
Product sizin	0.06	0.08	0.002	-
Total Plant	0.68	0.14	0.04	0.08

Fraction P2O 46% (2)

Emission Factors (lb/ton P2O5)

Process	Particulate	Ammonia	Fluoride	SO2
Reactor/Amm	3.30	-	0.11	-
Dryer/cooler	3.26	0.04	0.09	-
Product sizin	0.13	0.17	0.004	-
Total Plant	1.48	0.30	0.09	0.174

Emission Rate (lb/bu)

Process	Particulate	Ammonia	Fluoride	SO2

Reactor/Amm	6.47E-04	-	-	-
Dryer/cooler	6.39E-04	8.51E-06	-	-
Product sizin	2.55E-05	3.41E-05	8.51E-07	-
Total Plant	2.90E-04	5.96E-05	1.70E-05	3.41E-05

Note: For particulate and ammonia the total emission factor is not the sum of the process emission factors, but is instead an aggregate value from a different source. The EPA quality rating for these values is also high, as opposed to the process level values, for which it is low. As such, emissions for corn production are taken from the total plant row.

Table 39 Process Emissions from Nitric Acid Manufacture (used in ammonium nitrate manufacture)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Nitric acid is used in the manufacture of ammonium nitrate. Since these emissions are not included in the emissions from ammonium nitrate manufacture they are included here.

Emission Factors (lb/ton)

Source	NOx
Weak Acid P	57
New Source	3
Catalytic Reduction	
Natural Gas	0.4
Hydrogen	0.8
N.G./Hydroge	0.9
Extended Absorption	
Single-Stage	1.9
Dual-Stage P	2.1
Chilled Absor	2.2
High-Strengt	10

Ratio of HNO 0.79
(nitric acid to ammonium nitrate)
$NH_3 + HNO_3 \rightarrow NH_4NO_3$

Emission Factors (lb/ton ammonium nitrate)

Source	NOx
Weak Acid P	44.87
New Source	2.36
Catalytic Reduction	
Natural Gas	0.31
Hydrogen	0.63
N.G./Hydroge	0.71
Extended Absorption	
Single-Stage	1.50
Dual-Stage P	1.65
Chilled Absor	1.73
High-Strengt	7.87

Fraction N in 0.35

Emission Factors (lb/ton N)

Source	NOx
Weak Acid P	128.21
New Source	6.75
Catalytic Reduction	
Natural Gas	0.90
Hydrogen	1.80
N.G./Hydroge	2.02
Extended Absorption	
Single-Stage	4.27
Dual-Stage P	4.72
Chilled Absor	4.95
High-Strengt	22.49

Urea N: Amm	1.04 (unitless)
Urea N	50.98%
Ammonium N	49.02%

Emission (lb/bu)

Source	NOx
Weak Acid P	8.26E-03
New Source	4.35E-04
Catalytic Reduction	
Natural Gas	
Hydrogen	1.16E-04
N.G./Hydroge	1.30E-04
Extended Absorption	
Single-Stage	2.75E-04
Dual-Stage P	3.04E-04
Chilled Absor	3.19E-04
High-Strengt	1.45E-03
Total Excludi	9.84E-03

Notes: Uncontrolled emissions rates from weak acid plant tailgas are the only emissions that are significant relative to fuel related emissions from the corn production cycle. The uncon 19.38% of fuel related NOx emissions. While this would be a significant contribution many techniques are employed to reduce tail gas emissions including extended absorption and catalytic reduction. Also,New Source Performance Standards for nitrogen emissions (expressed as N2O) for new and modified plants are 3 lb/ton of nitric acid. At this emission rate the NOx contributions from nitric acid manufac 1.02% of fuel related NOx emissions. Lacking information to accurately estimate actual controlled emissions, they will be neglected.

Table 40 Process Emissions from the Manufacture of Phosphoric Acid

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.9-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Phosphoric acid used in fertilizer manufacture is produced primarily using a wet process method. The factors given below are for wet process manufacture.

Emission Factors (lb/ton P2O5)

Source	Fluoride Controlled	Uncontrolled
Reactor	3.80E-03	0.38
Evaporator	4.40E-05	0.0044
Belt Filter	6.40E-04	0.064
Belt Filter Va	1.50E-04	0.015
Gypsum Sett-		

Emission Rate (lb/bu)

Source	Fluorine Controlled	Uncontrolled
Reactor	7.44E-07	7.44E-05
Evaporator	8.62E-09	8.62E-07
Belt Filter	1.25E-07	1.25E-05
Belt Filter Va	2.94E-08	2.94E-06
Gypsum Sett-		
Total	9.08E-07	9.08E-05

Notes: Uncontrolled fluorine emissions from phosphoric acid manufacture are similar to controlled emissions from ammonium phosphate manufacture.
For phosphoric acid, the control efficiency used is 99%, similar to the value given for the use of baghouses in GTSP manufacture. On this basis controlled emissions from phosphoric acid manufacture are only about 1% of controlled emissions from phosphoric acid manufacture.
For the sake of consistency, and lack further data on the relative penetration of controls in this industry, the controlled emission rate is used.

Table 41 Process Emissions from Sulfuric Acid Manufacture (used in phosphoric acid manufacture)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Sulfuric acid is used in the manufacture of phosphoric acid which is used in the manufacture of phosphate fertilizers. Emission consist primarily of sulfur dioxide and acid mist. Sulfur dioxide emissions are primarily a function of the conversion efficiency from SO2 to SO3 in the plant.

Emission Factors (lb/ton sulfuric acid)

Conversion	ESO2 Emissions
93	96
94	82
95	70
96	55
97	40
98	26
99	14
99.5	7
99.7	4
100	0

		Source
Sulfuric Acid	2.87	Conversion factor for sulfuric acid to DAP provided by Joyce Ober, sulfur specialist, Bureau of Mines

Emission Factor (lb/ton P2O5)

Conversion	ESO2 Emissions
93	275.52
94	235.34
95	200.9
96	157.85
97	114.8
98	74.62
99	40.18
99.5	20.09
99.7	11.48
100	0

Emission Rate (lb/bu)

Conversion	ESO2 Emissions
93	0.0540
94	0.0461
95	0.0393
96	0.0309
97	0.0225
98	0.0146
99	0.0079
99.5	0.0039
99.7	0.0022
100	0.0000

Notes: Sulfur dioxide emissions are highly correlated with conversion efficiency. Typical conversion efficiencies are given in AP-42 as 95 to 98%. Sufur emissions can be controlled using standard sulfur capture technologies. New Source Performance Standards are also set quite low, at 4 lb/ton of product. Assuming that new plants comply with NSPS limits, but that old plants exist with higher emissions, the emission rate used here is at the upper end of conversion efficiency estimates.

Acid Mist Emission Factors (lb/ton H2SO4) (Where values are given as a range, the midrange is used)

Raw Materia	Uncontrolled	Controlled
Recovered S	0.574	-
Elemental Su	-	0.128
Bright Virgin	1.7	-
Dark Virgin S	3.3	2.06
Spent Acid	2.3	0.34

Acid Mist Emission Factors (lb/ton P2O5)

Raw Materia	Uncontrolled	Controlled
Recovered S	1.64738	-
Elemental Su	-	0.36736
Bright Virgin	4.879	-
Dark Virgin S	9.471	5.9122
Spent Acid	6.601	0.9758

Acid Mist Emissions (lb/bu)

Raw Materia	Uncontrolled	Controlled
Recovered S	3.23E-04	-
Elemental Su	-	7.19E-05
Bright Virgin	9.56E-04	-
Dark Virgin S	1.85E-03	1.16E-03
Spent Acid	1.29E-03	1.91E-04
Average	1.41E-03	6.15E-04
Average (Co	1.01E-03	

Notes: According to AP-42 about 81% of sulfuric acid production is from elemental sulfur burning. Average emission factors are calculated above using the elemental, bright virgin, and dark virgin sulfur factors.

The uncontrolled and controlled factors are then averaged.

Carbon Dioxi	8.1	lb/ton sulfuric acid
	23.247	lb/ton P2O5
	0.0046	lb/bu

Notes: Carbon dioxide emissions are negligible relative to other sources and are thus neglected.

Table 42 Air Emissions from Pesticide Use

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Section 9.2.2.

(2) Personal Communication with David Pike, Agriculture Extensionist, University of Illinois, Department of Agronomy, September 26, 1995.

(3) Personal Communication with Van Johnson, Pesticide Specialist, USDA NASS, September 28, 1995.

(4) Personal Communication with Bob Hartzler, Iowa Ag. Extension, University of Iowa, September 22, 1995.

(5) United States Department of Agriculture, Economic Research Service. 1994. Agricultural Resource and Environmental Indicators, USDA/ERS, Ag. handbook 705, Washington, D.C.

(6) Personal Communication with Tom Lapp, Midwest Research Institute, September 29, 1995.

Pesticide Types Used on Illinois Corn (2) Product formulation data was provided by Van Johnson of the USDA, NASS.

Pesticide Typ	Active Ingredient	Brand	Formulation Type	Formulation S	Alachlor	Atrazine	Fraction Prin	Fraction Inert Ingredient	Fraction of To	Normalized Fr	Pest. use/bu co	a.i. use/bu co	Atrazine/bu c	Total VOC's (lb/bu corn)
Herbicides	Alachlor	Bullet	liquid	4	2.5	1.5	29.99%	52.02%	30%	35.29%	4.72E-03	1.42E-03	8.49E-04	4.91E-04
		Lasso (4EC)	liquid	4	4	0	47.98%	52.02%	20%	23.53%	1.97E-03	9.43E-04	0.00E+00	2.05E-04
		Lariat (4F)	liquid	4	2.5	1.5	29.99%	52.02%	10%	11.76%	1.57E-03	4.72E-04	2.83E-04	1.64E-04
		Lasso Micro-	micro-encapsulat	4	4	0	47.98%	52.02%	25%	29.41%	2.46E-03	1.18E-03	0.00E+00	2.56E-04
									85%		1.07E-02	4.01E-03	1.13E-03	1.12E-03
					Metalachlor	Atrazine								
	Metalachlor	Dual 4E	liquid	4	4	0	47.98%	52.02%	50%	50.00%	5.11E-03	2.45E-03	0.00E+00	5.32E-04
		Bicep 6L	liquid	6	3.33	2.67	39.94%	28.03%	35%	35.00%	4.30E-03	1.72E-03	1.38E-03	2.41E-04
		Dual 25G	granular	0.25	25	0	25.00%	75.00%	15%	15.00%	2.94E-03	7.36E-04	0.00E+00	5.52E-04
									100%		1.24E-02	4.91E-03	1.38E-03	1.33E-03
					Atrazine	Other								
	Atrazine	Bicep 6L	liquid	6	2.67	3.33	32.03%	28.03%	25%	25.00%	4.30E-03	1.38E-03	1.38E-03	3.09E-04
		Atrazine 4L	liquid	4	4	0	47.98%	52.02%	52%	52.00%	6.76E-03	3.25E-03		7.04E-04
		Bullet	liquid	4	1.5	2.5	17.99%	52.02%	15%	15.00%	4.72E-03	8.49E-04	8.49E-04	6.04E-04
		Marksman	liquid	4	2.1	1.1	25.19%	52.02%	8%	8.00%	1.98E-03	4.99E-04		2.97E-04
									100%		1.78E-02	5.97E-03		
											Actual Atrazine	6.24E-03		
										Percent Accou	95.67%	Atrazine from	6.80E-04	1.91E-03
												Total Atrazin	2.91E-03	
												Total Atrazin	6.24E-03	
					Cyanazine	Atrazine								
	Cyanazine	Extrazine 4L	liquid	4	3	1	35.98%	52.02%	40%	42.11%	3.78E-03	1.36E-03	4.53E-04	3.93E-04
		Extrazine 90D	dry flowable	90	0.675	0.225	67.50%	10.00%	20%	21.05%	1.01E-03	6.80E-04	2.27E-04	2.82E-05
		Bladex 80WP	wettable powder	80	0.8	0	80.00%	20.00%	8%	8.42%	3.40E-04	2.72E-04	0.00E+00	1.70E-05
		Bladex 4L	liquid	4	4	0	47.98%	52.02%	12%	12.63%	8.50E-04	4.08E-04	0.00E+00	8.85E-05
		Bladex 90DF	dry flowable	90	0.9	0	90.00%	10.00%	15%	15.79%	5.67E-04	5.10E-04	0.00E+00	1.59E-05
									95%		6.54E-03	3.23E-03	6.80E-04	5.43E-04
Insecticides	Chlorpyrifos	Lorsban 15G	granular	15			0.15	85.00%	95%	100.00%	3.27E-02	4.91E-03	0	6.95E-03
	Fonofos	Dyfonate II 2	granular	20			0.2	80.00%	95%	100.00%	2.45E-02	4.91E-03	0	4.91E-03
	Turbufos	Counter (15G	granular	15			0.15	85.00%	80%	80.00%	2.62E-02	3.93E-03	0	5.56E-03

Counter 20C ?	20	0.2	80.00%	20%	20.00%	4.91E-03	9.81E-04	0	9.81E-04	
					Total Pesticid	1.36E-01		Total VOC's	2.33E-02	lb/bu

Notes: The above table is quite confusing, and I appologize for the convoluted estimation methodology. The complexity is caused by the fact that pesticides are often sold in formulations containing more than one active ingredient. Thus if you treat a 4L pesticide as having 4 lb/gallon of the primary a.i., you will end up double counting the inert portion since the pesticide is actually delivering two forms of a.i. which together sum to 4L. To account for this I added columns in which I calculate the quantity of pesticide used to deliver the appropriate amount of the primary a.i., based on the fraction of each brand used to meet the need for that a.i. These fractions were normalized to 100% to simulate complete coverage by the most important brands cited by Dave Pike. I then estimate the amount of atrazine, the secondary chemical, that comes along for the ride. Finally, I summed up the atrazine from combination forms in the atrazine section, instead of calculating it from the fraction of atrazine applied in various forms. I then modified the fractions for atrazine to try and balance the total atrazine use. This was done by raising the estimated fraction of atra 95.67% of actual use. I then delete the contribution of dual form atrazine formulations from the contribution to the VOC emissions, w 17.17% percent of total pesticide use (by gross pesticide wt.)

VOC emissions are estimated using the data below on the fraction of inert ingredient that are VOC's. These are applied to the total inert ingredient quantities calculated in the above table. Total VOC emissions are then summed. I have included VOC emissions from pesticides in the category non-methane organic compounds, which is a broader class of organics. For a good description of the classification of organics see AP-42 (1995) pages 6 and 7.

I should also note that I made some assumptions about the brands used to supply granular pesticides. Dave Pike did not give brand specific data for these, only the formulation type and strength. In most cases there is only one brand listed of each strength in the data provided by Van Johnson. Thus I used that particular brand data for the pesticide type and strength of interest.

Air Emissions

Active IngredFrom Table 2			Source: AP-42 Table 9.2.2-1		Source: AP-42 Table 9.2.2-4			Surface incorporation fraction estimated based on conversations with Bob Hartzler and Dave Pike.			
					Emission Fac	Emission Factor		Surface Application	Total Emissions		Percent of a.i. Volatilized
Pesticide	Use Rate	Units	Vapor Pressure	Units	Surface Applic	Soil Incorpor	Units	Fraction	Active Ingredi	Units	
Alachlor	4.01E-03	lb/bu corn	1.4E-05	mm Hg at 20	700	42	lb/ton	70%	1.01E-03	lb/bu	25.13%
Metholachlor	4.91E-03	lb/bu corn	3.1E-05	mm Hg at 20	700	42	lb/ton	70%	1.23E-03	lb/bu	25.13%
Atrazine	6.24E-03	lb/bu corn	2.9E-07	mm Hg at 20	700	5.4	lb/ton	85%	1.86E-03	lb/bu	29.79%
Cyanazine	3.23E-03	lb/bu corn	1.6E-09	mm Hg at 20	700	5.4	lb/ton	85%	9.62E-04	lb/bu	29.79%
Chlorpyrifos	7.34E-04	lb/bu corn	1.7E-05	mm Hg at 20	700	42	lb/ton	100%	2.57E-04	lb/bu	35.00%
Fonofos	2.57E-04	lb/bu corn	3.4E-04	mm Hg at 20	1160	104	lb/ton	100%	1.49E-04	lb/bu	58.00%
Terbufos	6.81E-04	lb/bu corn	3.2E-04	mm Hg at 20	1160	104	lb/ton	100%	3.95E-04	lb/bu	58.00%

Notes: Estimation method described in AP-42. There is some question of what the application method is for insecticides. They are applied using a planter attachment, and are in granular form. Rod Williamson of the Iowa Corn Growers Association suggests that the granules would thus end up at about the depth of the corn seed, or 1-2 inches. Discussions with Tom Lapp, who developed the section for EPA, suggest that this is not what is referred to as soil incorporated. Instead this is meant to apply to pesticides that are actually injected into the soil. This would more commonly occur with liquid or gaseous forms of pesticides. Accordingly the insecticides are treated as 100% surface application.

Average VOC Content of Pesticide Inert Ingredient Portion (1)

Liquid	20%
Wettable Pow	25%
Microencaps	23%
Dry Flowable	28%
Granule	25%

EOF

e (Ali and McBride 1994). This energy
Shapouri uses an energy use estimate
980). The exact value of 180,000 btu/lb does not appear
omparison of the 1980 estimates reveals
put hauling, suggesting at least some double
omparitive values in Green (1987). Both references
formation the more recent estimate is used. This result
y use for fertilizer manufacture is difficult to
Lorenz appear to rely on estimates
has been used in conjunction with data about
differ little. The Lorenz values are significantly
ng, and application, which would account for much of the difference.
focussed on international uses of fertilizers. Since most U.S.
timate of enery use for irrigation (18,000 Btu/bu), derived
rom 9 mid-western states to estimate on farm energy
account for much of the difference in over energy

Emissions by Sector and Type
(lb/bu)

Fraction of Emissions by S

Emission Cat	Tilling Opera (Table 26)	Nitrogenous Fuel Consum (Table 27)	Process Emis Ammonia Ma (Table 35)	Limestone Production (Table 24)	Phosphate R Processing (Table 34)	Farm Fuel Use (Table 29)	Corn Drying (Table 30)	Unallocated Emissions (Table 31)	Urea Manufacture (Table 36)	Ammonium N Manufacture (Table 37)	Ammonium P Manufacture (Table 38)	Phosphoric A Manufacture (Table 40	Sulfuric Acid Manufacture (Table 41)	Nitric Acid Manufacture (Table 39)	Pesticide Use (Table 42)	Total Emissions		Sum Excluding Nitric Acid MFG	
NOx	-	3.28E-03	-	0.00161	-	3.65E-02	4.01E-04	0.0008	-	-	-	-	-	9.84E-03	-	0.0524	NOx	0.0426	NOx
SOx	-	6.37E-06	3.59E-05	-	4.73E-06	2.31E-03	2.20E-06	0.0033	-	-	3.41E-05	-	1.46E-02	-	-	2.03E-02	SOx		SOx
PM-10	0.348	1.46E-04	-	-	1.36E-02	-	4.28E-05	0.0003	-	-	-	-	-	-	-	3.62E-01	PM-10		PM-10
CO	-	4.25E-04	0.0099	0.00138	2.33E-04	1.41E-01	8.09E-05	0.0002	-	-	-	-	-	-	-	1.53E-01	CO		CO
CO2	-	1.28	1.5259	0.29174	2.17E-01	2.11E+00	8.76E-01	0.6238	-	-	-	-	-	-	-	6.93E+00	CO2		CO2
Non-Methane	-	1.50E-05	0	-	-	-	2.56E-05	0.0000	-	-	-	-	-	-	2.33E-02	2.33E-02	Non-Methane VOC's		Non-Methane
Methane	-	3.07E-06	-	-	-	-	7.04E-06	0.0000	-	-	-	-	-	-	-	1.98E-05	Methane		Methane
Particulate	-	-	-	-	-	3.74E-03	1.24E-06	0.0005	-	-	2.90E-04	-	-	-	-	4.48E-03	Particulate		Particulate
Hydrocarbon	-	-	-	0.00043	-	9.57E-03	-	-	-	-	-	-	-	-	-	1.00E-02	Hydrocarbons		Hydrocarbon
Aldehydes	-	-	-	-	-	4.70E-04	-	-	-	-	-	-	-	-	-	4.70E-04	Aldehydes		Aldehydes
Ammonia	-	-	0.0026	-	-	-	-	-	0.00480008	6.71E-03	5.96E-05	-	-	-	-	1.42E-02	Ammonia		Ammonia
Nitric Acid	-	-	-	-	-	-	-	-	-	1.97E-04	-	-	-	-	-	1.97E-04	Nitric Acid		Nitric Acid
Fluoride	-	-	-	-	-	-	-	-	-	-	1.70E-05	9.08E-07	-	-	-	1.79E-05	Fluoride		Fluoride
Acid Mist	-	-	-	-	-	-	-	-	-	-	-	-	1.01E-03	-	-	1.01E-03	Acid Mist		Acid Mist

h only the

ighting times emission factor

	Gas Trucks			Light Duty Diesel				Heavy Diesel Trucks			
	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx
1	0	0	0		0	0	0		0	0	0
2	0.3944	1.7952	0.612		0.0408	0.1632	0.1224		0.34	1.1288	1.5096
3	0.3596	1.6936	0.5568		0.0464	0.1392	0.1044		0.3016	1.0556	1.334
4	0.3168	1.5444	0.4851		0.0396	0.1287	0.099		0.2673	0.9801	1.188
5	0.289	1.4025	0.4335		0.034	0.1105	0.085		0.238	0.8925	1.037
6	0.2592	1.2744	0.3888		0.036	0.1008	0.072		0.2088	0.7992	0.9
7	0.2294	1.1408	0.341		0.031	0.0868	0.0682		0.186	0.7192	0.7874
8	0.2014	1.0123	0.2968		0.0265	0.0742	0.0583		0.1643	0.6413	0.6837
9	0.1755	0.8865	0.2565		0.0225	0.0675	0.0495		0.144	0.5625	0.5895
10	0.1824	1.5808	0.1976		0.0228	0.057	0.0418		0.1254	0.5016	0.6802
11	0.1716	1.6566	0.1716		0.0198	0.0495	0.0396		0.132	0.4521	0.6006
12	0.3584	4.4296	0.1568		0.0168	0.0448	0.0448		0.1568	0.4144	0.5292
13	0.312	3.8496	0.1344		0.0144	0.0384	0.0384		0.1368	0.3624	0.4536
14	0.262	3.304	0.114		0.012	0.032	0.034		0.116	0.308	0.378
15	0.2376	3.0204	0.1026		0.0126	0.0306	0.0306		0.1206	0.3042	0.369
16	0.207	2.7375	0.0915		0.0105	0.0255	0.0285		0.102	0.258	0.3075
17	0.1807	2.4024	0.0793		0.0182	0.0312	0.0247		0.0949	0.2626	0.3224
18	0.2013	2.3221	0.0704		0.0154	0.0275	0.022		0.0814	0.2255	0.2728
19	0.1782	2.1717	0.0657		0.0135	0.0225	0.018		0.0675	0.1863	0.2232
20	0.8955	10.9485	0.333		0.0675	0.1125	0.09		0.3375	0.9405	1.116
	5.412	49.1729	4.8874		0.5003	1.3424	1.0712		3.3209	10.9948	13.2817

4.91E-04

10.40%

ector

Tilling Opera (Table 26)	Nitrogenous Fuel Consum (Table 27)	Process Emis Ammonia Ma (Table 35)	Limestone Production (Table 24)	Phosphate R Processing (Table 34)	Farm Fuel Use (Table 29)	Corn Drying (Table 30)	Unallocated Emissions (Table 31)	Urea Manufacture (Table 36)	Ammonium N Manufacture (Table 37)	Ammonium P Manufacture (Table 38)	Phosphoric A Manufacture (Table 40	Sulfuric Acid Manufacture (Table 41)	Nitric Acid Manufacture (Table 39)	Pesticide Use (Table 42)	Total Emissions	
-	8%	-	4%	-	86%	1%	2%	-	-	-	-	-	19%	-	100%	NOx
-	0%	0%	-	0%	11%	0%	16%	-	-	-	-	72%	-	-	100%	SOx
96%	0%	-	-	4%	-	0%	0%	-	-	-	-	-	-	-	100%	PM-10
-	0%	6%	1%	0%	92%	0%	0%	-	-	-	-	-	-	-	100%	CO
-	18%	22%	4%	3%	30%	13%	9%	-	-	-	-	-	-	-	100%	CO2
-	0%	0%	-	-	-	0%	0%	-	-	-	-	-	-	99.78%	100%	Non-Methane VOC's
-	16%	-	-	-	-	36%	49%	-	-	-	-	-	-	-	100%	Methane
-	-	-	-	-	83%	0%	10%	-	-	6%	-	-	-	-	100%	Particulate
-	-	-	4%	-	96%	-	-	-	-	-	-	-	-	-	100%	Hydrocarbons
-	-	-	-	-	100%	-	-	-	-	-	-	-	-	-	100%	Aldehydes
-	-	18%	-	-	-	-	-	34%	47%	-	-	-	-	-	100%	Ammonia
-	-	-	-	-	-	-	-	-	100%	-	-	-	-	-	100%	Nitric Acid
-	-	-	-	-	-	-	-	-	-	95%	5%	-	-	-	100%	Fluoride
-	-	-	-	-	-	-	-	-	-	-	-	100%	-	-	100%	Acid Mist

Sheet Title: Corn Transportation and Storage Last Modified 10/03/95

Sheet Description:

This sheet includes the life-cycle inventory components for the transport of corn from the producer to a refining facility, including intermediate storage and processing common with corn. Contrary to some literature assumptions about the primary mode of transport, because of the large volumes of corn consumed at typical facilities, the primary mode is rail. Corn is also most commonly shipped to a grain elevator for storage before shipping to the mill. At the grain elevator several processing operations are carried out. The impact of these operations is included here.

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9	Fumigant and Grain Protectant Use in Grain Storage
10	Particulate Emissions from Uncontrolled Grain Elevators

Summary Output:

Allocated LCI components		Units	Quantity	DQI	Notes:
Air					
	Particulates	lb/bu	2.41E-01	3	Dominated by grain handling, emission factor quality average.
	SOx	lb/bu	4.33E-04	3	Based on old emission factor data.
	CO	lb/bu	2.37E-03	3	Based on old emission factor data.
	CO2	lb/bu	4.70E-01	3	Based on old emission factor data.
	Hydrocarbons	lb/bu	1.03E-03	3	Based on old emission factor data.
	NOx	lb/bu	4.49E-03	3	Based on old emission factor data.
	Aldehydes	lb/bu	6.70E-05	3	Based on old emission factor data.
	Organic Acids	lb/bu	4.25E-05	3	From train transport. Old data but quality rating good.
Water		None			
Solid Wastes		None			
Resource Use	Diesel	Btu/bu	2,920	3	Detailed estimate

	Table 6 Train Transport
Particulates	1.52E-04
SOx	3.46E-04
CO	7.89E-04
CO2	1.36E-01
Hydrocarbons	5.70E-04
NOx	2.24E-03
Aldehydes	3.34E-05
Organic Acids	4.25E-05

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source:	Notes:
Gallons Ethanol	Btu	84,600	btu_gallon	5	
Gallon Ethanol	lb	6.58	lb_gallon	25	Specific Gravity = .7893
Gallon Ethanol	bu	0.4	bu_gallon	6	Depending on plant and process may range from .385 to .40.
Btu	Joules	1,055	Joules_btu	11	
kg	lb	2.20	lb_kg	11	
bu	lb	56	lb_bu		
kcal	btu	3.968	btu_kcal	11	
sq. miles	acres	640	acres_sqmile	11	
short tons	lb	2,000	lb_shortton	11	
Barrels	gallons	42	gallons_barrel	19	
Gallon Gasoline	btu	125,071	btu_gallongas	19	
Gallon Diesel	btu	138,690	btu_gallondies	19	
Cubic Feet N.G.	btu	1,031	btu_cubicft	19	

Molecular Wts.

Element/Compound	Name	Wt.	Defined Name
C	Carbon	12.01	
O	Oxygen	16.00	
CO2	Carbon Dioxide	44.01	
Ratio CO2:C		3.66	carbon_ratio

Calculations

Table 1 Energy Use in Transporation: Estimates as cited in DeLuchi (1993)

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

LCI component	Reference	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units	Transformed Quan.	Transformed Std. Dev.
Transporation Energy Use	Giampietro and Pimen	Btu/Btu-ethanol	0.06			Btu/bu	12,690	
	Chambers et al. (1979	Btu/Btu-ethanol	0.09			Btu/bu	19,035	
	Parisi (1983)	Btu/Btu-ethanol	0.1			Btu/bu	21,150	
	Pimentel (1990)	Btu/Btu-ethanol	0.07			Btu/bu	14,805	
	DeLuchi (1993)	Btu/Btu-ethanol	0.03			Btu/bu	6,345	

Notes: DeLuchi states in Table K-7 that all data are referenced to the higher heating value of ethanol, and gives transporattion energy consumption estimates as a function of btu/btu ethanol. I transform these estimates to btu/bu, then give the values as they appear in the actual reference for those references which I have, below.

Calculations

Table 2 Energy Use in Transporation Estimates

Parisi, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42--68 (1983).

Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy, Science, vol. 206, November 1979, pp. 789-795.

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

Unnasch, Stefan. 1990. Greenhouse Gas Emissions from Ethanol Production and Vehicle Use, Acurex Corp. for the National Corn Growers Association.

LCI component	Raw/ Input Units	Raw/ Input Quan.	Transformed Units	Transformed Quan.	Notes:
Energy to Transport Corn to Mill	kcal/2700 kg	325,000	Btu/bu	12,132	Pimentel et al. (1988). Estimated as 10% of the
	Btu/bu	21,000	Btu/bu	21,000	Chambers et al. (1979) cites ACR (1978) (unp
	MJ/kg ethanol	2.93	Btu/bu	20,727	Parisi cites Chambers (1979)
	MJ/kg ethanol	0.45	Btu/bu	3,183	Parisi cites Scheller (1978)
	Btu/lb	5,600	Btu/bu	5,600	DeLuchi (1993) calculated based on truck tran
	Btu/bu	4,000	Btu/bu	4,000	Unnasch (1990)
		Average of Scheller, DeLuchi, Pimentel, Unnasch, and Chambers Estimates.		9,183	
			Standard Deviation	7,484	

Notes: The variability in literature estimates of energy use in corn transportation is high. The value arrived at in the calculation below is also much smaller than these estimates 2,920 btu/lb. Since most of the above estimates were made using crude assumptions, this value is used.

Table 3 Iowa Corn Transportation Statistics

(1) Iowa Department of Agriculture and Land Stewardship. 1991. Grain Marketing: Iowa, Iowa Department of Agriculture.

(2) Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

(3) Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

(4) Baumel, C. Philip, unpublished data, Iowa State University, Ames, Iowa.

Grain Merchandised by Elevators/Grain Dealers (1)
Domestic Processing

	Method Shipped Truck	Rail	Barge	
Percent of Bushels	38.1%	61.7%	0.2%	
Average Distance (miles)	58	281	ND	

Grain Shipped by Farmers to Country Elevators (3)

Vehicle Type	Percent	Average 1-way Distance
Semi tractor-trailor	32%	8
Tandem axle truck	29%	13.5
Single axle truck	9%	9.3
Tractor - one wagon	20%	6.3
Tractor - two wagons	10%	6.3

Grain Shipped Directly from Farm to Processor — Source:
Percent of total grain processed 20% (4)

Vehicle Type	Percent	Average Distance	Notes:
Tandem Axle	5%	58	Assumed to be the same as average distance from elevator to farmer
Semi	95%	58	Assumed to be the same as average distance from elevator to farmer

Notes: According to this model, 80% of corn processed domestically is shipped first to an elevator, then to the processor. The remaining 20% is shipped straight from farm to processor, which includes some corn sold to the elevator but transported directly to the processor.

Table 4 Energy Intensity of Corn Transportation Modes

(1) Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

(2) Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

(3) Baumel, C. Philip, unpublished data, Iowa State University, Ames, Iowa.

Energy Intensity of Corn Transportation Modes

Mode	Intensity	Units	Source:	Fuel	Transformed Intensity	Units	Capacity	Units	Capacity	Units
Rail	640.1	Net Ton-mi/gallon	(1)	Diesel	22,861	Net Bu-mi/gallon				
Semi trucks	90.5	Net Ton-mi/gallon	(1)	Diesel	3,232	Net Bu-mi/gallon	950	bu	53,200	lb
Tandem axle trucks	37.8	Net Ton-mi/gallon	(2)	Diesel	1,350	Net Bu-mi/gallon	600	bu	33,600	lb
Single axle trucks	30.2	Net Ton-mi/gallon	(2)	Gasoline	1,079	Net Bu-mi/gallon	300	bu	16,800	lb
Tractor - 1-300 bushel wagon	12.6	Net Ton-mi/gallon	(3)	Diesel	450	Net Bu-mi/gallon	300	bu	16,800	lb
Tractor - 2-300 bushel wagons	25.2	Net Ton-mi/gallon	(3)	Diesel	900	Net Bu-mi/gallon	600	bu	33,600	lb

Notes: Energy intensity estimates in terms of net ton-miles per gallon account for the actual tonnage hauled and the distance traveled unloaded (backhaul). Thus bushel-miles per gallon cannot be used to calculate a real mileage, since they include unloaded miles.

Table 5 Derived Total Transportation Requirements for Corn

From Table 3

Mode	Distance (1-way)	Units	Energy	Units
Railroad	138.70	Miles	841.5	Btu/bu
Semi tractor-trailor	28.70	Miles	1,231.4	Btu/bu
Tandem axle truck	3.71	Miles	381.3	Btu/bu
Single axle truck	0.67	Miles	77.6	Btu/bu
Tractor - one wagon	1.01	Miles	310.7	Btu/bu
Tractor - two wagons	0.50	Miles	77.7	Btu/bu
Total			2,920.2	Btu/bu

Notes: In this table, the transportation modes, distances, intensity, and fractions have been used to generate what could be called the average bushel transportation requirements. This does not imply that any single bushel actually travels the above distances for each mode. Instead it is a way

of representing the average requirements to transport corn.

Table 6 Emissions from Train Transport

(1) U.S. EPA, AP-42, Table II-2.1 (1985)

(2) U.S. DOE/EIA. 1994. Annual Energy Review: 1993, DOE/EIA-0384(93).

(3) DOE/EIA. 1994. Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573

Energy Intensity	841	Btu/bu	From Table Above
	0.0061	Gallons/bu	

Emission Factors - Railway	Raw Input Quantity	Units	Source	Transformed Quantity	Units
Particulates	25	lb/1000 gal fuel	(1)	0.18	lb/million btu
SOx	57	lb/1000 gal fuel	(1)	0.41	lb/million btu
CO	130	lb/1000 gal fuel	(1)	0.94	lb/million btu
CO2	19.95	kg/million btu	(4)	161.16	lb/million btu
Hydrocarbons	94	lb/1000 gal fuel	(1)	0.68	lb/million btu
NOx	370	lb/1000 gal fuel	(1)	2.67	lb/million btu
Aldehydes	5.5	lb/1000 gal fuel	(1)	0.04	lb/million btu
Organic Acids	7	lb/1000 gal fuel	(1)	0.05	lb/million btu

Emissions	Quantity	Units
Particulates	1.52E-04	lb/bu
SOx	3.46E-04	lb/bu
CO	7.89E-04	lb/bu
CO2	1.36E-01	lb/bu
Hydrocarbons	5.70E-04	lb/bu
NOx	2.24E-03	lb/bu
Aldehydes	3.34E-05	lb/bu
Organic Acids	4.25E-05	lb/bu

Table 7 Emissions from Truck Transportation

(1) Davis, Stacy C. 1994. Transportation Energy Data Book: Edition 14, Oak Ridge National Laboratory, ORNL-6798.

(2) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

(3) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(4) U.S. DOE/EIA. 1994. Annual Energy Review: 1993, DOE/EIA-0384(93).

(5) United States Environmental Protection Agency. 1985. Compilation of Air Pollutant Emission Factors, AP-42 Fourth Edition.

Estimated Transport Distance

	Distance	Units	Energy	Units
Semi	28.70	Miles	1,231.44	Btu/bu
Tandem Axle	3.71	Miles	381.35	Btu/bu
Single Axle	0.67	Miles	77.65	Btu/bu

Estimated Vehicle Load

			Notes:
Semi	53,200	lb	Data provided by Philip Baumel
Tandem Axle	33,600	lb	Data provided by Philip Baumel
Single Axle	16,800	lb	Data provided by Philip Baumel

Vehicle Registration Mix: January 1 & emissions factors , g/mile (5)

	Gas Trucks				Light Duty Diesel				Heavy Diesel Trucks			
Model Year	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	
Model Year - 1	0	2.8	12.6	4.4	0.008	0.3	1.2	0.9	0.031	2.4	7.9	
Model Year - 2	0.136	2.9	13.2	4.5	0.006	0.3	1.2	0.9	0.007	2.5	8.3	
Model Year - 3	0.116	3.1	14.6	4.8	0.008	0.4	1.2	0.9	0.008	2.6	9.1	
Model Year - 4	0.099	3.2	15.6	4.9	0.011	0.4	1.3	1	0.01	2.7	9.9	
Model Year - 5	0.085	3.4	16.5	5.1	0.017	0.4	1.3	1	0.012	2.8	10.5	
Model Year - 6	0.072	3.6	17.7	5.4	0.023	0.5	1.4	1	0.014	2.9	11.1	
Model Year - 7	0.062	3.7	18.4	5.5	0.029	0.5	1.4	1.1	0.017	3	11.6	
Model Year - 8	0.053	3.8	19.1	5.6	0.035	0.5	1.4	1.1	0.021	3.1	12.1	
Model Year - 9	0.045	3.9	19.7	5.7	0.041	0.5	1.5	1.1	0.025	3.2	12.5	
Model Year - 10	0.038	4.8	41.6	5.2	0.047	0.6	1.5	1.1	0.03	3.3	13.2	
Model Year - 11	0.033	5.2	50.2	5.2	0.053	0.6	1.5	1.2	0.036	4	13.7	
Model Year - 12	0.028	12.8	158.2	5.6	0.059	0.6	1.6	1.6	0.043	5.6	14.8	
Model Year - 13	0.024	13	160.4	5.6	0.065	0.6	1.6	1.6	0.051	5.7	15.1	
Model Year - 14	0.02	13.1	165.2	5.7	0.071	0.6	1.6	1.7	0.061	5.8	15.4	
Model Year - 15	0.018	13.2	167.8	5.7	0.077	0.7	1.7	1.7	0.073	6.7	16.9	
Model Year - 16	0.015	13.8	182.5	6.1	0.083	0.7	1.7	1.9	0.088	6.8	17.2	
Model Year - 17	0.013	13.9	184.8	6.1	0.089	1.4	2.4	1.9	0.105	7.3	20.2	
Model Year - 18	0.011	18.3	211.1	6.4	0.095	1.4	2.5	2	0.126	7.4	20.5	
Model Year - 19	0.009	19.8	241.3	7.3	0.101	1.5	2.5	2	0.151	7.5	20.7	
Model Year - 20	0.045	19.9	243.3	7.4	0.027	1.5	2.5	2	0	7.5	20.9	
Weighted Average	92.20%	5.9	53.3	5.3	94.50%	0.5	1.4	1.1	90.90%	3.7	12.1	

Emission Factors		Raw Input Quantity	Units	Transformed Input Quantity	Units
Gas Truck	Hydrocarbons	5.9	g/mile	0.0129	lb/mi
	Carbon Monoxide	53.3	g/mile	0.1176	lb/mi
	NOx	5.3	g/mile	0.0117	lb/mi
Light Diesel Truck	Hydrocarbons	0.5	g/mile	0.0012	lb/mi
	Carbon Monoxide	1.4	g/mile	0.0031	lb/mi
	NOx	1.1	g/mile	0.0025	lb/mi
Heavy Diesel Truck	Hydrocarbons	3.7	g/mile	0.0081	lb/mi
	Carbon Monoxide	12.1	g/mile	0.0267	lb/mi
	NOx	14.6	g/mile	0.0322	lb/mi
CO2 Emission Factors	Gas	19.4	kg/million btu	156.79	lb/million btu
	Diesel	20.0	kg/million btu	161.16	lb/million btu

Emissions		Heavy Diesel	Light Diesel	Gas	Total	Units
	Hydrocarbons	0.00024	7.22087E-06	2.88839E-05	0.000279415	lb/bu
	Carbon Monoxide	0.00081	1.9375E-05	0.000262436	0.00108736	lb/bu
	NOx	0.00097	1.54607E-05	2.60841E-05	0.001014646	lb/bu
	CO2	0.19845	0.061456568	0.012174601	0.2720858	lb/bu

Notes: The three categories of trucks used in corn transportation were arbitrarily assigned to the three categories of trucks for which emissions factors are available in AP-42. There is some danger in this since the AP-42 emission factors are given in terms of g/mi. Clearly the size assumptions about the truck categories in AP-42 would have a significant impact on the emission factors in terms of grams/mi. Closer examination of AP-42 reveals that the light truck category refers to vehicles with gross weights between 6,000 and 8,500 lbs. This suggests that the BMI load estimate of 10,000 lb is high. Unfortunately the resolution of the AP-42 data is poor. The category large trucks includes all vehicles over 8,500 lbs. Thus, while the large vehicle capacity of 42,000 lb is confirmed as being reasonable fo trucks used to haul corn, this would seem to fall at the high end of the large truck category in AP-42. Lacking more detailed truck emission factors, these estimates will be used.

Table 8 Emissions from Tractor Transport

(1) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

(2) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573

Estimated Energy Usage

	Energy	Units	Fuel	Units
Tractor - one wagon	311	btu/bu	0.00224	Gallons/bu
Tractor - two wagons	78	btu/bu	0.00056	Gallons/bu

Total		388 btu/bu		0.0028 Gallons/bu						
Farm Equipment Emission Factors	Units	Raw Input Quantity							Source	Notes
		HC	CO	NOx	SOx	Particulate	Aldehydes			
Diesel Tractors	lb/1000 gallons	63.55	175	438.59	31.2	45.7	12		(1)	Weighted by factors for large 2WD, small 2WD, and 4WD tractors.

Carbon Dioxide Emission Factor	Quantity	Units	Source
Diesel	19.95	kg/million btu	(2)
	161.16	lb/million btu	

Emissions

	Quantity	Units
Hydrocarbons	1.78E-04	lb/bu
CO	4.90E-04	lb/bu
NOx	1.23E-03	lb/bu
SOx	8.74E-05	lb/bu
Particulate	1.28E-04	lb/bu
Aldehydes	3.36E-05	lb/bu
CO2	0.06	lb/bu

Notes: In this table, emission factors for diesel tractors have been used for all tractor transport. While on farm energy consumption estimates suggest that some gasoline is used, it is not possible to determine the amount of gasoline used in tractors. Since some transport is carried out by light trucks, and since some of these trucks may be gas powered, it is assumed here that assigning diesel emission factors to tractor transport is a reasonable approximation. The impact of this assumption is primarily on the carbon monoxide estimates, for which gas tractors have an extremely high emission factor. Lacking additional data, the diesel tractor assumption will be used.

Table 9 Fumigant and Grain Protectant Use in Grain Storage

Personal Communication, C.L. Storey, Consultant on Protection of Stored Grains, July 27, 1995.

United States Department of Agriculture, Office of Pesticide Research. 1987. Biologic and Economic Assessment of Stored Corn, Wheat, and Peanut Fumigants in The Biologic and Economic Assessment of Registered Fumigants, USDA Office of Pesticide Research, Washington, D.C.

Aluminum Phosphide Use: 1987

Off Farm	Total Use	Units	Corn Treated	Units	Use Rate	Units
	20,790	kg	415.8	million Bushels	1.10E-04	lb/bu

Percent of Corn Bushels Treated
20.7%

Aluminum Phosphide use per Total Bushels
2.28E-05 lb/bu

For many reasons, the use of chemicals to protect stored grain is negligible. Corn carries a lenient standard relative to grains such as wheat, on the number of insects allowed per unit measure before the grain is classified as weevily. About 65-70% of corn also never leaves the region in which it was produced, which limits storage and transportation times, again limiting the need for chemical treatment. Finally, the use of chemical protectants is very small relative to the use of insecticides and herbicides applied in the field.

Though several different types of fumigants were once used with corn, many of these have not been re-registered by the EPA. These include Methyl Bromide, which is an ozone depleting substance, and well as chloropicrin and magnesium phosphide. The only fumigant currently in use in significant quantities is aluminum phosphide. This substance produces a phosphine gas which is toxic to both insects and humans, and is suspected of causing genetic abnormalities in cell tissue. Charles Storey estimates that less than 10% of corn is fumigated.
Of grain protectants, actelic (parimifos methyl) is the only important one used on corn. Again, the use of this substance is estimated to be very small.

Table 10 Particulate Emissions from Uncontrolled Grain Elevators

U.S. EPA. 1985. AP-42 Compilation of Air Pollutant Emission Factors,4th Edition
Chapter 6.4-1.

Emission Factors	Process	Quantity	Units
Country Elevators	Unloading	0.6	lb/ton

	Loading	0.4	lb/ton		
	Removal From Bins	2	lb/ton		
	Drying	0.2	lb/ton		
	Cleaning	0.4	lb/ton		
	Headhouse	5	lb/ton	Tranformed Quantity	Units
	Total	8.6	lb/ton	0.2408	lb/bu
Inland Terminal Elevators	Unloading	1	lb/ton		
	Loading	0.4	lb/ton		
	Removal From Bins	2.8	lb/ton		
	Drying	0.2	lb/ton		
	Cleaning	0.6	lb/ton		
	Headhouse	4.6	lb/ton		
	Tripper (Gallery Belt)	1.6	lb/ton		
	Total	11.2	lb/ton		
				Tranformed Quantity	Units
Average		9.9	lb/ton	0.2772	lb/bu

Notes: These emission factors account for the quantity of grain processed by each operation per unit of grain shipped. This ranges from as low as 0.1 to as high as 3.1. These data indicate that about 30% of grain received at country elevators is dried at the elevator, compared to 10% of received grain being dried at at inland terminal elevators. Since corn bound for domestic processing usually passes only through country elevators, the emission factors for country elevators are used. It is assumed that all energy use for drying is accounted for in the corn production sheet.

EOF

Table 7 Truck Transport	Table 8 Tractor Transport	Table 12 Grain Handling	Total
-	1.28E-04	2.41E-01	0.24108
-	8.74E-05	-	0.000433
1.09E-03	4.90E-04	-	0.002366
2.72E-01	6.26E-02	-	0.470276
2.79E-04	1.78E-04	-	0.001028
1.01E-03	1.23E-03	-	0.004488
-	3.36E-05	-	6.7E-05
-	-	-	4.25E-05

	Table 6 Train Transport	Table 7 Truck Transport	Table 8 Tractor Transport	Table 12 Grain Handling	Total
Particulates	0%	#VALUE!	0%	100%	100%
SOx	80%	#VALUE!	20%	#VALUE!	100%
CO	33%	46%	21%	#VALUE!	100%
CO2	29%	58%	13%	#VALUE!	100%
Hydrocarbons	55%	27%	17%	#VALUE!	100%
NOx	50%	23%	27%	#VALUE!	100%
Aldehydes	50%	#VALUE!	50%	#VALUE!	100%
Organic Acids	100%	#VALUE!	#VALUE!	#VALUE!	100%

e energy input to corn production, including energy in fertilizers, etc.
ublished).

sport 80 miles roundtrip plus occaisional train transport bringing total energy to 200,000 Btu/ton.

Transformed Intensity	Units
6.1	Btu/Bu-mile
42.9	Btu/Bu-mile
102.7	Btu/Bu-mile
116.0	Btu/Bu-mile
308.2	Btu/Bu-mile
154.1	Btu/Bu-mile

Product of weighting times emission factor

		Gas Trucks			Light Duty Diesel				Heavy Diesel Trucks			
NOx	Model Year	Total Hydro.	CO	NOx	Fraction	Total Hydro.	CO	NOx	Fraction	Total Hydro	CO	NOx
11	Model Year -1	0	0	0		0	0	0		0	0	0
11.1	Model Year - 2	0.3944	1.7952	0.612		0.0408	0.1632	0.1224		0.34	1.1288	1.5096
11.5	Model Year - 3	0.3596	1.6936	0.5568		0.0464	0.1392	0.1044		0.3016	1.0556	1.334
12	Model Year - 4	0.3168	1.5444	0.4851		0.0396	0.1287	0.099		0.2673	0.9801	1.188
12.2	Model Year - 5	0.289	1.4025	0.4335		0.034	0.1105	0.085		0.238	0.8925	1.037
12.5	Model Year - 6	0.2592	1.2744	0.3888		0.036	0.1008	0.072		0.2088	0.7992	0.9
12.7	Model Year - 7	0.2294	1.1408	0.341		0.031	0.0868	0.0682		0.186	0.7192	0.7874
12.9	Model Year - 8	0.2014	1.0123	0.2968		0.0265	0.0742	0.0583		0.1643	0.6413	0.6837
13.1	Model Year - 9	0.1755	0.8865	0.2565		0.0225	0.0675	0.0495		0.144	0.5625	0.5895
17.9	Model Year - 10	0.1824	1.5808	0.1976		0.0228	0.057	0.0418		0.1254	0.5016	0.6802
18.2	Model Year - 11	0.1716	1.6566	0.1716		0.0198	0.0495	0.0396		0.132	0.4521	0.6006
18.9	Model Year - 12	0.3584	4.4296	0.1568		0.0168	0.0448	0.0448		0.1568	0.4144	0.5292
18.9	Model Year - 13	0.312	3.8496	0.1344		0.0144	0.0384	0.0384		0.1368	0.3624	0.4536
18.9	Model Year - 14	0.262	3.304	0.114		0.012	0.032	0.034		0.116	0.308	0.378
20.5	Model Year - 15	0.2376	3.0204	0.1026		0.0126	0.0306	0.0306		0.1206	0.3042	0.369
20.5	Model Year - 16	0.207	2.7375	0.0915		0.0105	0.0255	0.0285		0.102	0.258	0.3075
24.8	Model Year - 17	0.1807	2.4024	0.0793		0.0182	0.0312	0.0247		0.0949	0.2626	0.3224
24.8	Model Year - 18	0.2013	2.3221	0.0704		0.0154	0.0275	0.022		0.0814	0.2255	0.2728
24.8	Model Year - 19	0.1782	2.1717	0.0657		0.0135	0.0225	0.018		0.0675	0.1863	0.2232
24.8	Model Year - 20	0.8955	10.9485	0.333		0.0675	0.1125	0.09		0.3375	0.9405	1.116
14.6	sum	5.412	49.1729	4.8874		0.5003	1.3424	1.0712		3.3209	10.9948	13.2817

Sheet Title: Corn Wet Milling Last Modified 10/04/95

Sheet Description:

This sheet contains an inventory of the wet corn milling process. The process inputs and outputs are normalized to one bushel of corn input. Energy intensity estimates for wet corn milling are derived from 1991 MECS data for SIC 2046. This industry includes manufacturers of wheat, potato, and tapioca starch, as well as corn starch and other corn wet milling products. Though the industry has relatively high coverage (.95) and specialization (.88) ratios (U.S. Department of Commerce 1994), the industry does produce significant quantities of ethanol, a relatively energy intensive product. Most public literature on material consumption by the industry separates out materials used for ethanol production. Energy use estimates contained in MECS do not make this distinction, however. In order to use the MECS data it is necessary to allocate some fraction of energy consumption to the production of potato, wheat, and tapioca starch, as well as ethanol production. The first two tables in this sheet deal with the allocation of energy consumption to these products. Table 3 then uses the adjusted MECS data to develop an energy balance for the wet corn milling industry.

There are also several co-products of glucose (or corn starch, depending on the desired end product). These include corn oil, and animal feeds. Inputs and outputs of the industry must be allocated between these products. This has been done on this sheet on the basis of product dry weight. Thus the right hand column gives the inputs and outputs per pound of product output, which can be applied to any of the products and coproducts.

Some data was derived in these estimates from publicly available databases. Because these datasets are fairly large, they have been included on separate sheets of the file. Sheet two contains the raw TRI data. Sheet three contains power plant coal ash content data. Sheet 4 contains power plant sulfur content data.

NREL has developed a process model for a wet corn mill to provide glucose for the BDO process. The starch conversion component of this model was only recently completed, and so while the results are often included here for comparison purposes, insufficient time was available to reconcile differences. Some of these are fairly significant. For example energy use in the NREL model is only about half that estimated based on public data. The estimates based on public data are crude enough to suggest that this discrepancy may be an overestimate. Again, the time frame for completion of the module limit our ability to further explore the source of these differences.

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List of Tables:

Summary Output:

Allocated LCI components		Units	Unallocated Quantity	Units	Allocated Quantity	Data Quality Indicator	Comments
Air	NOx	lb/bu	0.048	lb/lb product	9.72E-04	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	SOx	lb/bu	0.052	lb/lb product	1.06E-03	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	PM-10	lb/bu	0.032	lb/lb product	6.41E-04	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	Total Particulate	lb/bu	0.086	lb/lb product	1.74E-03	2	Large variations in uncontrolled and controlled values.
	CO	lb/bu	0.044	lb/lb product	8.91E-04	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	CO2	lb/bu	15.62	lb/lb product	3.18E-01	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	Non-Methane Org. Com	lb/bu	1.73E-04	lb/lb product	3.51E-06	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	Methane	lb/bu	1.52E-04	lb/lb product	3.09E-06	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	N2O	lb/bu	0.013	lb/lb product	2.72E-04	2	Driven by AP-42 data on fluidized bed coal combustion, data qu
	HCL	lb/bu	3.57E-04	lb/lb product	7.26E-06	3	Based on aggregate TRI data for several years.
	Ammonia	lb/bu	8.85E-05	lb/lb product	1.80E-06	3	Based on aggregate TRI data for several years.
	Chlorine	lb/bu	3.91E-05	lb/lb product	7.95E-07	3	Based on aggregate TRI data for several years.
	Sulfuric Acid	lb/bu	2.41E-05	lb/lb product	4.90E-07	3	Based on aggregate TRI data for several years.
Water	Total Water Emission	gallons/bu	30	gallons/lb product	0.61	3	Typical estimate. No assessment of statistical reliability.
	Ammonia	lb/bu	2.80E-04	lb/lb product	5.70E-06	3	Based on aggregate TRI data for several years.
	Chlorine	lb/bu	1.60E-06	lb/lb product	3.26E-08	3	Based on aggregate TRI data for several years.
	BOD5	lb/bu	0.020	lb/lb product	4.07E-04	3	Based on CFR regulations for new Facilitites.
	TSS	lb/bu	0.025	lb/lb product	5.09E-04	3	Based on CFR regulations for new Facilitites.
Solid Wastes	HCL	lb/bu	5.50E-06	lb/lb product	1.12E-07	3	Based on aggregate TRI data for several years.

	Ammonia	lb/bu	9.00E-06	lb/lb product	1.83E-07	3	Based on aggregate TRI data for several years.
	Coal Ash	lb/bu	0.64	lb/lb product	1.30E-02	3	Estimated from information on typical mid-west utility coal.
Resource Cons	N.G.	Btu/bu	40,479	Btu/lb product	823	2	No current process specific data available. Derived from industr
	Coal	Btu/bu	52,255	Btu/lb product	1,063	2	No current process specific data available. Derived from industr
	Electricity	Kwh/bu	3.38	Kwh/lb product	0.069	2	No current process specific data available. Derived from industr
	Water	gallons/bu	35	Gallons/lb product	0.712	2	Typical estimate. No assessment of statistical reliability.
	Sulfur	lb/bu	0.06	lb/lb product	0.0012	3	Modeled estimate conforms with other published estimates.
Outputs	Total	lb/bu	49.16	Percent	100.00%	4	Material balance based on large sample and current data, and c
	Glucose	lb/bu	32.17	Percent	65.45%	4	Material balance based on large sample and current data, and c
	Corn Oil	lb/bu	0.95	Percent	1.94%	4	Material balance based on large sample and current data, and c
	Gluten Feed	lb/bu	13.60	Percent	27.67%	4	Material balance based on large sample and current data, and c
	Gluten Meal	lb/bu	2.43	Percent	4.94%	4	Material balance based on large sample and current data, and c

Conversion Factors

Unit from	Unit to	Multiplier	Name	Source	
bu	lb	56	lb_bu		
Hectares	acre	2.47	acre_ha	15	
kg	lb	2.20	lb_kg	15	
hectares	sq. meters	10,000	sqmeters_ha	15	
meter	feet	3.28	feet_meter	15	
short tons	lb	2,000	lb_shortton	15	
kcal	btu	3.97	btu_kcal	15	
Joules	btu	9.47E-04	btu_joule	15	
Gallons Ethano	lb	6.58	lb_gallon	34	Specific Gravity = .7893
Gallons Ethano	bu	0.4	bu_gallon	11	Depending on plant and process may range from .385 to .40.
Hectares	Sq. cm	1.00E+08	sqcm_ha	15	
cubic cm	liters	0.001	liters_ccm	15	
liters	gallons	0.264	gallons_liter	15	
sq mile	acres	640	acres_sqmile	15	
metric tons	short tons	1.10	shortton_metricton	15	
Gallon Ethanol	Btu	84,600	Btu_gallon	10	
Gallons	liters	3.7854	liters_gallon	15	
Gallons water	lb	8.35	lb_gallonw	15	
Tons of Coal	Million Btu	22,276,000	btu_toncoal	25	

Molecular Wts.	Element/Compound	Name	Wt.	Defined Name
	Ca	Calcium	40.080	
	O	Oxygen	15.999	
	S	Sulfur	32.060	
	CaSO4	Calcium Sulfate	96.058	
	C	Carbon	12.011	

CO2	Carbon Dioxide	44.010	
Ratio CaSO4:S		4.246	gypsum_ratio
Ratio CO2:Ca		1.098	calcium_ratio
Ratio CO2:S		1.373	sulfur_ratio
Ratio CO2:C		3.66	carbon_ratio
Ratio S:SO2		0.50	sulfoxide_ratio

Calculatio --

Table 1 Ethanol Production: 1991

(1) USDA/ERS.1993. Feed Situation and Outloook Report.

(2) National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

(3) Data provided by Kathy Bryan, Consultant to Ethanol Industry

(4) Marland, G., and A. Turhollow. 1990. Carbon Dioxide Emissions from Production and Combustion of Fuel Ethanol from Corn, Oak Ridge National Laboratory, ORNL/TM-11180.

(5) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

(6) Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

(7) Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

(9) Jones, K.W. 1989. Operation Case Histories of the South Point Ethanol and Kentucky Agricultural Energy Corporation Fuel Ethanol Plants in, Energy from Biomass and Wastes XII, D.L. Klass (ed.), Institute of Gas Technology, pp. 1343-1375.

	Raw Input Quantity	Units	Source		
Corn Grind for A	429	Million Bu	(1)		
Ethanol per bu	2.5	Gallons/bu	(2)		
Gallons Ethano	1072.5	Million Gallons	(calculated)		
% Capacity of C	49.70%		(3)		
Estimated Prod	533	Million Gallons	(calculated)		
Energy Intensity	49,504	Btu/gallon	(see below)	49504	Btu/gallon
	1.36	Kwh/gallon	(see below)	4637	Btu/gallon
Energy Consum	26.39	Trillion Btu	(calculated)	26.39	Trillion Btu
	724	Million Kwh	(calculated)	2.47	Trillion Btu

Notes: Corn use data is typically based on the corn marketing year, which, like the DOE fiscal year, begins September 1. I have used the 1990/91

marketing year data to estimate corn grind for alcohol production in 1991.

Estimates of Energy Intensity of Ethanol Production

Raw Input Quantity	Units	Source	Range from	to	Transformed Input Quantity	Units	Range from	to	Units
17.11	MM J/kg	(4)	14.11	20.11	48,366	Btu/gallon	39,885	56,846	Btu/gallon
0.32	kwh/liter				4,133	Btu/gallon			
0.525	Btu/Btu Ethanol	(5)	0.35	0.6	44,415	Btu/gallon	29,610	50,760	Btu/gallon
0.05	Btu/Btu Ethanol	(electricity)			4,230	Btu/gallon			
41,000	Btu/gal	(6)	34,000	48,000	41,000	Btu/gallon	34,000	48,000	Btu/gallon
1.50	kwh/gallon				5,118	Btu/gallon			
0.55	Btu/Btu Ethanol	(7)			46,530	Btu/gallon			
1.26	kwh/gallon				4,299	Btu/gallon	Notes:		
16,329	tons coal	(9)			67,351	Btu/gallon	South Point Ethanol in October 1984		
7,236,232	kwh				4,572	Btu/gallon			
5,400,744	gallons ethanol								
4,670	tons coal	(9)			49,361	Btu/gallon	Kentucky Ag. Energy plant in July 1987		
3,378,600	kwh				5,470	Btu/gallon			
2,107,511	gallons ethanol								
			Average		49,504	Btu/gallon	Fuel		
					4,637	Btu/gallon	Electricity		
					1.36	kwh/gallon	Electricity		

Notes: Ethanol energy intensity estimates vary more widely than is indicated by this data. I have tried to use the most recent data available for which both fuel and electricity estimates are given separately. Where possible I have used electricity estimates given in kwh/unit ethanol to avoid errors in converting to btus. I then convert to btus using the convention of 3412 btu/kwh.

Table 2 Production of Potato and Wheat Starch in SIC 2046

(1) CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

(2) Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

(3) Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

(4) Personal Communication, Damon Horn, A.E. Staley, Stanfield, OR.
Personal Communication, Mick Persinger, Penwest, Richland, WA.

Most potato starch plants purchase a slurry from other processing facilitities (e.g. A.E. Staley, Stanfield and Murtaugh plants, and Penwest, Richland and Idaho Falls plants). Energy is consumed in motors and dryers. Assuming that the drying energy dominates, we can calculate an energy intensity per lb based on data from A.E. Staley, Stanfield.

		Raw Input Quantity	Units	Source	Notes:
Purchased Slurry					
Slurry Density		22	Baume	(4)	Damon Horn provided me with detailed estimates of the operating parameters of a mill which dries purchases s
Approximate Solids		36%		(4)	
Centrifuge to					
Cake Moisture		42.00%		(4)	
Dry to					
Final Moisture		12.50%		(4)	
Dryer Operation					
Input	Water	63,362	lb/day	(calculated)	
	Starch	87,500	lb/day	(calculated)	
	Total	150,862	lb/day	(calculated)	
Output	Water	12,500	lb/day	(calculated)	
	Starch	87,500	lb/day	(calculated)	
	Total	100,000	lb/day	(4)	
Dryer RemovesWater		50,862	lb/day	(calculated)	
Enthalpy of Vaporization at 212 F		970.30	Btu/lb	(1)	
Specific Heat of Water		1	Btu/F	(2)	
Temp in		70	F	(estimate)	
Temp out		212	F	(estimate)	
Energy to dry starch		1,112	Btu/lb water evaporate	(calculated)	
Total Energy		56,573,879	Btu	(calculated)	
Intensity		566	Btu/lb dry starch	(calculated)	
Dryer Rating		7	million Btu/hr	(4)	This estimate was carried out as a check on the other method. While 90% efficinecy
Capacity		60%		(4)	may be a little high for a starch dryer, for the level of accuracy needed here
Effective Input		4.2	million Btu/hr	(calculated)	this provides and acceptable concurrence to the above energy intensity estimate.
Daily Operation		15	hours	(4)	
Output		100,000	lb	(4)	
Total Energy/lb		630	Btu/lb	(calculated)	
Efficiency		89.8%		(calculated)	
Potato Starch Production 1992					
		0.207	Billion lb	(3)	
Energy Use					

	1.30E+11 Btu	(calculated)
	0.130 T Btu	(calculated)

Estimate Wheat Starch Energy Intensity from Potato

None of the wheat starch mfgs would give me any info on energy. Ken Smick at ADM did say that they dry wheat starch from 35-40% solids down to 12% moisture content.

Wheat Starch Production 1992		
	0.276 Billion lb	(3)
Energy Use		
	1.74E+11 Btu	(calculated)
	0.174 T Btu	(calculated)
Same for Tapioca		
Tapioca Starch Production 1992		
	0.069 Billion lb	(3)
Energy Use		
	4.35E+10 Btu	(calculated)
	0.043 T Btu	(calculated)
Total Potato, Wheat, and Tapioca Starch Energy		
	0.348 T Btu	(calculated)

Notes: Based on these estimates the total energy use for starch drying is quite small. Assuming that there is additional electrical energy consumption, and that some facilities produce potato starch from potatoes instead of a slurry, the total energy consumption may be as much as double this value, which is still negligible relative to total energy use in SIC 2046.

Table 3 Wet Corn Mill Energy Balance

(1) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(2) USDA/ERS. 1994. Sugar and Sweetner: Situation and Outlook Report, SSSV 19N2, June 1994.

(3) Divine, T.E., D.P. Alzheimer, and W.F. Smith. 1977. Estimates of Process Energy Use in Four Key Food Products Industries, presented at the 1977 Annual Meeting of the Pacific Northwest Region American Society of Agricultural Engineers, Pendelton, OR, September 7-9, 1977.

Notes: Based on 1991 MECS energy consumption for all purposes. Electricity data is taken from Table 4. Energy use is rounded to eliminate minor fuels, then adjusted to account for energy use in ethanol production.

1991 Corn Grin 811 MM Bu (2)

Total Primary Consumption of Fuel for All Purposes (MECS Table 1)
(Trillion Btu)

Fuel	Raw Input Quantity	Rounded Input Quantity	Less Ethanol Energy	Adj. Total	Energy per Bushel (Btu)

R. Oil	0.18	0	0	0	0
D. Oil	0.17	0	0	0	0
N.G.	52	55	12	43	53,615
LPG	0.004	0	0	0	0
Coal	68	71	15	56	69,212
Coke, Breeze and Other	6	0	0	0	0
Electricity					
Purchased	14	14	2	12	15,293
Sold	0	0	0	0	0
Conv. Gen.	6	6	1	5	6,519
Renew. Gen.	0	0	0	0	0
Net Fuel	126	126	26	100	122,827
Net Electric	20	20	2	18	21,812

Energy Intensity of Production - SIC 2046

Energy Consumed	100	Tbtu		
Grind	811	MM bushels		
Fuel Energy Intensity	122,827	Btu/bu	2,193	Btu/lb
Electric Energy Intensity	15,293	Btu/bu	4.48	Kwh/lb
Fraction of energy used for starch processing and syrup concentra	24.5%	(3)		
Fuel Intensity of Glucose Production	92,735	Btu/bu	1,656	Btu/lb
Electric Intensity of Glucose Production	11,547	Btu/bu	0.06	Kwh/lb

Notes: Significant processing of starch and glucose products (such as glucose concentration or starch modification) occurs in wet corn mills.
To try and account for the most energy intensive aspects of this processing, the fraction of energy used for these processes from reference 7 has been deducted from the total wet mill energy intensity estimate. While this is a rather crude method, lacking additional data it will have to suffice.

Fuel Split								
Natural Gas		40,479	Btu/bu	40,479	Btu/bu	723	Btu/lb	43.65%
Coal		52,255	Btu/bu	52,255	Btu/bu	933	Btu/lb	56.35%
Electricty	Purchased	11,547	Btu/bu	3.38	Kwh/bu	6.04E-02	Kwh/lb	
	Generated	1,597	Btu/bu	0.47	Kwh/bu	8.36E-03	Kwh/lb	

Other EstimatesTotal	4,100	Btu/lb	(3)	229,600	Btu/bu
Less Syrup Concentration, starch drying, and dextr	3,096	Btu/lb	(3)	173,376	Btu/bu

	kg steam	kg corn	lb steam/lb corn	lb steam/bu	Btu/bu	Btu/lb
NREL Estimate	507,182,742	579,078,355	0.88	49.05	44,658	797
Assuming 80% efficiency boilers total fu		997				

	Electricity Use (kwh/yr)	Starch Use (kg/yr)	Corn Use to Produce S	Energy Intensity (kwh/kg	Energy Intensity (kwh/lb corn)
NREL Electricit	2,524,789	110,225,570	184,690,076	0.014	0.030

Because the NREL data has only recently been provided, and is still in the process of being updated, it was not possible to resolve the differences in estimates.

Notes: Based on this estimate the energy intensity of wet corn milling has dropped significantly since 1977. This seems fairly reasonable in such a long time frame. It can also be compared to the energy intensity estimate for ethano 2,417 Btu/lb. This suggests that our estimate is at least in the ballpark for corn processing at wet mills.

Table 4 Electricity Balance in Wet Corn Milling Industry

Electricity Balance. Raw Input Data from MECS Tables 4, 16, 17. All data in million Kwh.
Estimated values (mine) are in bold type. Calculated values are in italics.
Tranfers in are assumed to equal zero. Thus purchases equal the sum of purchases and transfers in. Sales can be calculated for the Midwest and U.S. regions as the difference between columns E and K. Next, conventional generation can be calculated for the Midwest and U.S. regions from columns J - C + I. Finally conventional generation in the West and South must be estimated. If the ratio of generation to purchases is assumed to be the same in these two regions, successive guesses can be made until the relationship is balanced. Using 15 million kwh conv. generation in the West, the remaining values can be calculated, giving a reasonable balance to the table.

Region	Table 4 Purchases	Transfers In	Table 4 P&T in	Table 16 Gen. (conv.)	Table 17 Gen. (renew.)	E + F Total Onsite Gen.	Table 16 Sales and Transfers	Table 16 P&Tin + Gen - Sale Net Demand	Table 4 P&Tin + Renew. - Sale Net Electricity
West	93	0	93	15	0	15	0	108	93
South	837	0	837	134	0	134	82	889	755
Midwest	3,199	0	3,199	1,617	0	1,617	7	4,809	3,192
Northeast	15	0	15	0	0	0	0	15	15
U.S.	4,143	0	4,143	1,766	0	1,766	89	5,820	4,054
U.S. (Quads)	14.14	0.00	14.14	6.03	0.00	6.03	0.30	19.86	13.83

ratio generation to purchases		Balance Net Demand
West	0.161	1
South	0.160	

Table 5 Emissions from Energy Consumption In Wet Corn Mills

(1) U.S. EPA, AP-42, Sections 1.1 and 1.4

(2) Personal Communication, Bob Bessette, Council of Industrial Boilers, 6-16-95.

(3) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(4) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

(5) Utility Data Institute. 1995. EEI Power Statistics Database.

Emission Facto	Fuel	Pollutant	Category	Raw Input Quantity	Units	Source	Notes	Transformed Input Quantity
	Gas							
		NOx						
			Uncontrolled	550	lb/million cubic feet	(1)		0.53346
			Low NOx	81	lb/million cubic feet	(1)		0.07856
			Flue Gas Recirc.	53	lb/million cubic feet	(1)		0.05141
		NOx	Average	308.5	lb/million cubic feet			0.29922
		SO2		0.6	lb/million cubic feet	(1)		0.00058
		PM-10		13.7	lb/million cubic feet	(1)	Data are for small industrial boilers.	0.01329
		CO		40	lb/million cubic feet	(1)	Uncontrolled emission factor. No data fo	0.03880
		CO2		14.47	million m tons carbon/Q	(4)	Data are for small industrial boilers	116.88885
		Non-Methane VOC's		1.411	lb/million cubic feet	(1)		0.00137
		Methane		0.289	lb/million cubic feet	(1)		0.00028
		N2O		0	lb/million cubic feet	(1)		
	Coal Heat Content			22.276	Million btu/ton	(3)		
	Coal							
		NOx		15.2	lb/ton	(1)		0.68235
		SO2		22.1	lb/ton	(1)		0.99356
		PM-10		13.2	lb/ton	(1)		0.59257
		CO		18	lb/ton	(1)		0.80804
		CO2		25.58	million m tons carbon/Q	(4)		206.63558
		Non-Methane VOC's		0.05	lb/ton	(1)		0.00224
		Methane		0.06	lb/ton	(1)		0.00269
		N2O		5.7	lb/ton	(1)	Average of values for bubbling and circu	0.25588

SO2 emission factor estimate for fluidized bed coal boilers

SO2 emissions can be calculated as SO2 = 39.6*S*(Ca/S)^-1.9 where S is the sulfur percentage of the coal, and Ca/S is the calcium to sulfur ratio in the bed.

Ca/S	2.2	(ratio)	(2)
Sulfur percent	2.50	percent	(estimate)
SO2	22.1	lb/ton	(calculated)
	0.99	lb/mm btu	(calculated)

Fuel Related En	Quantity	Units
NOx	0.04777	lb/bu
SO2	0.05194	lb/bu
PM-10	0.03150	lb/bu

CO	0.04380	lb/bu
CO2	15.52937	lb/bu
Non-Methane V	0.00017	lb/bu
Methane	0.00015	lb/bu
N2O	0.01337	lb/bu

Notes: According to Bob Bessett, fluidized bed boilers are the most common type used in this industry. Emissions from coal are thus estimated based on emission factors for this technology. Because fluidized bed boilers remove sulfur, it is possible to burn much higher sulfur content coal without surpassing limits on sulfur emissions. For utilitites in Iowa, Illinois and Indiana, the average sulfur content of coal used was around 1.5% in 1993 (5). I assume a sulfur content of 2.50 percent to account for the use of cheap, high sulfur coal in FBC boilers.

Table 6 Toxic Releases from The Wet Corn Milling Industry

(1) U.S. EPA, Toxic Release Inventory, Data downloaded from Right To Know (RTK) Network online database. (Raw data on sheet TOXICS)

(2) USDA/ERS.1993. Feed Situation and Outloook Report.

This Table includes data only on emissions of four toxics. For information on why other toxics categories were exluded, see the sheet TOXICS.

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	Ammonia Fug Air	Stack Air	Water	Land
1987	1104	416,721	1,000	50,250	50,459
1988	1160	68,669	3,686	161,420	250
1989	1221	81,151	5,052	710,368	1,450
1990	1221	19,706	8,332	776,472	6,865
1991	1318	18,264	5,384	427,024	13,576
1992	1375	16,252	4,437	266,877	0
1993	1413	71,687	1,725	56,649	0
Total		692,450	29,616	2,449,060	72,600

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Year	Grind (million bu)	HCL Fug Air	Stack Air	Water	Land
1987	1104	16,578	20,996	0	4,750
1988	1160	11,331	7,870	0	750
1989	1221	16,055	32,073	11	1,011
1990	1221	14,241	34,203	5	1,000
1991	1318	12,987	1,261,725	600	27,000
1992	1375	7,214	955,691	250	200
1993	1413	12,010	977,391	0	15,910
Total		90,416	3,289,949	866	50,621

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Chlorine

Year	Grind (million bu)	Fug Air	Stack Air	Water	Land
1987	1104	1,500	0	250	0
1988	1160	3,670	10,252	250	0
1989	1221	7,172	12,000	250	0
1990	1221	2,755	10	1,277	0
1991	1318	2,501	159,896	11,176	0
1992	1375	1,267	155,055	1,433	0
1993	1413	2,487	4,887	1	1
Total		21,352	342,100	14,637	1

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Sulfuric Acid

Year	Grind (million bu)	Fug Air	Stack Air	Water	Land
1987	1104	1,002	538	13	0
1988	1160	1,751	1,013	0	0
1989	1221	1,504	791	0	0
1990	1221	1,032	59	755	0
1991	1318	268	61	0	0
1992	1375	272	104,443	0	0
1993	1413	532	120,459	5	1,182
Total		6,361	227,364	773	1,182

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Ammonia

Year	Grind (million bu)	Fug Air	Stack Air	Water	Land
1987	1104	3.77E-04	9.06E-07	4.55E-05	4.57E-05
1988	1160	5.92E-05	3.18E-06	1.39E-04	2.16E-07
1989	1221	6.65E-05	4.14E-06	5.82E-04	1.19E-06
1990	1221	1.61E-05	6.82E-06	6.36E-04	5.62E-06
1991	1318	1.39E-05	4.08E-06	3.24E-04	1.03E-05
1992	1375	1.18E-05	3.23E-06	1.94E-04	0
1993	1413	5.07E-05	1.22E-06	4.01E-05	0
Average		8.51E-05	3.37E-06	2.80E-04	9.00E-06

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

HCL

Year	Grind (million bu)	Fug Air	Stack Air	Water	Land

1987	1104	1.50E-05	1.90E-05	0	4.30E-06
1988	1160	9.77E-06	6.78E-06	0	6.47E-07
1989	1221	1.31E-05	2.63E-05	9.01E-09	8.28E-07
1990	1221	1.17E-05	2.80E-05	4.10E-09	8.19E-07
1991	1318	9.85E-06	9.57E-04	4.55E-07	2.05E-05
1992	1375	5.25E-06	6.95E-04	1.82E-07	1.45E-07
1993	1413	8.50E-06	6.92E-04	0	1.13E-05
Average		1.05E-05	3.46E-04	9.29E-08	5.50E-06

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Year	Grind (million bu)	Chlorine Fug Air	Stack Air	Water	Land
1987	1104	1.36E-06	0.00E+00	2.26E-07	0
1988	1160	3.16E-06	8.84E-06	2.16E-07	0
1989	1221	5.87E-06	9.83E-06	2.05E-07	0
1990	1221	2.26E-06	8.19E-09	1.05E-06	0
1991	1318	1.90E-06	1.21E-04	8.48E-06	0
1992	1375	9.21E-07	1.13E-04	1.04E-06	0
1993	1413	1.76E-06	3.46E-06	7.08E-10	7.08E-10
Average		2.46E-06	3.66E-05	1.60E-06	1.01E-10

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Year	Grind (million bu)	Sulfuric Acid Fug Air	Stack Air	Water	Land
1987	1104	9.08E-07	4.87E-07	1.18E-08	0
1988	1160	1.51E-06	8.73E-07	0	0
1989	1221	1.23E-06	6.48E-07	0	0
1990	1221	8.45E-07	4.83E-08	6.18E-07	0
1991	1318	2.03E-07	4.63E-08	0	0
1992	1375	1.98E-07	7.60E-05	0	0
1993	1413	3.77E-07	8.53E-05	3.54E-09	8.37E-07
Average		7.53E-07	2.33E-05	9.05E-08	1.20E-07

Notes: for some emission pathways and pollutants the quantities are very small, and may be the result of a single emission from a single plant in a particular year. The resulting emission intensity thus becomes rather low. I have reset these values to zero since they represent outliers, and since the impact at such low levels of emission would be neglibible. These include land emissions of chlorine, sulfuric acid, and HCL, and water emissions of HCL and sulfuric acid. Some of the remaining emissions may still be of negligible quantity.

Table 7 Particulate Emissions from Corn Milling Operations

(1) U.S. EPA, AP-42, Table 6.4-6.

(2) U.S. EPA. 1980. Source Category Survey: Starch Manufacturing Industry, EPA-450/3-80-040

(3) U.S. EPA. 1981. Source Category Survey: Animal Feed Dryers, EPA-450/3-81-017

(4) Grogan, P.J., and D. J. Santini. 1981. Overview of Environmental Problems in the Food Industry, in Proceedings of the 36th Industrial Waste Conference, May 12-14, 1981, Lafayette, IN.

(5) U.S. EPA, AP-42, Table 9.9.7-1.

Process Operation		Emission Factor	Units	Source	Notes	Transformed Quantity	Units	Notes:
Receiving	Uncontrolled	1	lb/ton	(1)		0.02800	lb/bushel corn	Converted based on the lb of corn per bush
Handling	Uncontrolled	5	lb/ton	(1)		0.14000	lb/bushel corn	Converted based on the lb of corn per bush
Cleaning	Uncontrolled	6	lb/ton	(1)		0.16800	lb/bushel corn	Converted based on the lb of corn per bush
Drying	Uncontrolled	0.48	lb/ton	(1)		0.01344	lb/bushel corn	Drying of Corn. Thus this factor is converte
Bulk Loading								
Grain Receiving	Fabric Filter	0.033	lb/ton	(5)		0.00092	lb/bushel corn	Converted based on the lb of corn per bush
Grain Handling	Uncontrolled	0.87	lb/ton	(5)		0.02436	lb/bushel corn	Converted based on the lb of corn per bush
Grain Cleaning	Uncontrolled	1.6	lb/ton	(5)		0.04480	lb/bushel corn	Converted based on the lb of corn per bush
Grain Cleaning	Cyclone	0.17	lb/ton	(5)		0.00476	lb/bushel corn	Converted based on the lb of corn per bush
Gluten Feed Dr	Direct-Rotary w/cyclone	0.27	lb/ton	(5)		0.00184	lb/bushel corn	Converted based on the fraction of feed pro
Gluten Feed Dr	Indirect-Rotary w/cyclon	0.49	lb/ton	(5)		0.00333	lb/bushel corn	Converted based on the fraction of feed pro
Gluten Drying	Direct-Rotary w/cyclone	0.27	lb/ton	(5)		0.00033	lb/bushel corn	Converted based on the fraction of feed pro
Gluten Drying	Indirect-Rotary w/cyclon	0.49	lb/ton	(5)		0.00059	lb/bushel corn	Converted based on the fraction of feed pro
Animal Feed Dr	Controlled	0.71	lb/ton	(2)	Gives a range of value	0.00483	lb/bushel corn	Converted based on the fraction of feed pro
	Controlled	2.6	lb/ton	(2)		0.01768	lb/bushel corn	Converted based on the fraction of feed pro
	Uncontrolled	14.2	lb/ton	(2)	Based on assumed co	0.09658	lb/bushel corn	Converted based on the fraction of feed pro
	Uncontrolled	52	lb/ton	(2)	of 95%/	0.35366	lb/bushel corn	Converted based on the fraction of feed pro
Handling	Controlled	0.02	lb/ton	(2)		0.00056	lb/bushel corn	Converted based on the lb of corn per bush
	Uncontrolled	0.41	lb/ton	(2)	Based on assumed co of 95%/	0.01148	lb/bushel corn	Converted based on the lb of corn per bush
Animal Feed Dryers (from plant level test data)								
	Controlled	0.71	lb/ton	(2)	These are a series of p	0.00483	lb/bushel corn	Converted based on the fraction of feed pro
		2.6	lb/ton	(2)	level data reported for	0.01768	lb/bushel corn	Converted based on the fraction of feed pro
		1	lb/ton	(2)	dryer types. Clearly the	0.00680	lb/bushel corn	Converted based on the fraction of feed pro
		0.005	lb/ton	(2)	above for controlled em	0.00003	lb/bushel corn	Converted based on the fraction of feed pro
		0.97	lb/ton	(2)	came from here.	0.00660	lb/bushel corn	Converted based on the fraction of feed pro
		10.4	lb/ton	(2)		0.07073	lb/bushel corn	Converted based on the fraction of feed pro
	Mean	2.61	lb/ton	(2)		0.01778	lb/bushel corn	Converted based on the fraction of feed pro
	Median	0.985	lb/ton	(2)		0.00670	lb/bushel corn	Converted based on the fraction of feed pro

Animal Feed Dryers

(from test and pControlled	0.3	lb/ton	(3)	There is clearly someth	0.00204	lb/bushel corn	Converted based on the fraction of feed pro
Controlled	0.7	lb/ton	(3)	this data. Not only are	0.00476	lb/bushel corn	Converted based on the fraction of feed pro
				lower than controlled factors, but the			
Uncontrolled	0.2	lb/ton	(3)	average recommended	0.00136	lb/bushel corn	Converted based on the fraction of feed pro
Uncontrolled	1	lb/ton	(3)	than the range of test a	0.00680	lb/bushel corn	Converted based on the fraction of feed pro
				values.			
Uncontrolled	10	lb/ton	(3)		0.06801	lb/bushel corn	Converted based on the fraction of feed pro
Total Particulate Emissions	1.3	lb/ton	(4)	Range of values	0.03640	lb/bushel corn	Converted based on the lb of corn per bush
	17.9	lb/ton	(4)		0.50120	lb/bushel corn	Converted based on the lb of corn per bush

Emission Values Used

Receiving	0.5165	lb/ton	Average of controlled and uncontrolled values.	0.01446	lb/bushel corn	Converted based on the lb of corn per bush
Handling	0.33	lb/ton	Average of controlled values averaged with unco	0.00924	lb/bushel corn	Converted based on the lb of corn per bush
Cleaning	0.885	lb/ton	Average of controlled and uncontrolled values.	0.02478	lb/bushel corn	Converted based on the lb of corn per bush
Drying	0.845	lb/ton	Average of controlled values. This may understa	0.00575	lb/bushel corn	Converted based on the fraction of feed pro
Total			emissions significantly.	0.05423	lb/bushel corn	

Notes: for most emission categories the difference between controlled and uncontrolled is not too dramatic. Thus the lack of data on the prevalence of controls is not a serious problem. For drying, however, the range of values is quite large, or aboutf two orders of magnitude. Clearly the assumption about how to estimate the prevalance of controls on feed dryers is important. I used the average of 6 controlled values, assuming controls are common.

Table 8 Water Emissions from the Wet Corn Milling Industry

(1) Grogan, P.J., and D. J. Santini. 1981. Overview of Environmental Problems in the Food Industry, in Proceedings of the 36th Industrial Waste Conference, May 12-14, 1981, Lafayette, IN.

(2) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(3) Code of Federal Regulations, 40 CFR 406.15, 1994 edition.

		Raw Input Quantity							
Water		Low	High	Average	Units		Source	Notes	Transformed Quantity
	Quantity		0.75	10	4.4	gallons/ton	(1)	Based on early 1970's data	0.1232
	BOD5		4.2	25	14.8	lb/ton	(1)	Based on early 1970's data	0.4144
	TSS		1	19.6	7.5	lb/ton	(1)	Based on early 1970's data	0.21
Water	Quantity		25	35	30	gallons/bu	(2)		30
	BOD5		1000	3000	2000	ppm	(2)	before treatment	0.5007
	TSS				500	ppm	(2)		0.028
EPA Limits	BOD5				20	lb/k bu	(3)	Standards of performance for	0.02
(30 day average	TSS				25	lb/k bu	(3)	new sources, after treatment	0.025

pH	6.0	9.0	(3)

Table 9 Water Consumption in Wet Corn Mills

(1) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(2) NREL Model

Water Use		Raw Input Quanitity	Units	Source:	Transformed Quantity	Units	Notes:
		30-40	Gallons/bu	(1)	35	Gallons/bu	Average of estimated range
	Process	1.43	kg water/kg corn	(2)	10	Gallons/bu	
	Cooling Tower	16.58	kg water/kg corn	(2)	111	Gallons/bu	

Table 10 Material Balance in Wet Corn Mills

(1) Corn Refiners Association, Inc. 1994?. 1994 Corn Annual, Corn Refiners Association, Washington, D.C.

(2) Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

(3) USDA/ERS. 1994. Sugar and Sweetner: Situation and Outlook Report, SSSV 19N2, June 1994.

(4) U.S. Department of Commerce, Bureau of the Census. 1994. 1992 Census of Manufactures: Grain Mill Products, MC92-I-20D(P).

(5) Whistler, R. L., J.N. BeMiller, and E.F. Paschall (ed.). 1984. Starch: Chemistry and Technology, Academic Press, NY.

(6) National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

(7) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(8) Austin, George T. 1984. Shreve's Chemical Process Industries, fifth edition, McGraw Hill, New York.

Shipments of Corn Refining Products (MRaw Input Quantity					Transformed Input Quantity			
Source	(1)	(2)	(3)	(3)	(1)	(2)	ERS 1992 (3)	ERS 1993 (3)
Units	Million lbs	Million lbs	Thousand sh tons dry	Thousand sh tons dry wt.	Million lbs	Million lbs	Million lbs	Million lbs
Year	1993	1992	1992	1993	1993	1992		
CORN STARCH	5,556	6,340			5,556	6,340		
SYRUPS	26,955				26,955			
HFCS 42	8,140		2,812	2,951	8,140		7,921	8,313
HFCS 55	10,441		3,871	4,198	10,441		10,055	10,904
HFCS TOTAL	18,580		6,683	7,149	18,580		17,976	19,217
TOTAL DOMES	32,511				32,511			

TOTAL EXPOR	739		739		Average
CORN OIL	799		799		
G. FEED, C. OI	11,388		11,388	Notes:	The Corn Refiners only
GLUTEN MEAL	2,031		2,031		their members. ERS es
STEEPWATER	458		458		this percentage is the e
TOTAL SHIPME	47,926		47,926		

CORN STARCH	6340	6340
WHEAT STARCH	276	276
POTATO STARCH	207	207
TAPIOCA STARCH	69	69
TOTAL STARCH	6,892	6892

Notes: Information is presented here from three sources for comparison. Based on the ERS and Corn Refiners data it appears that Corn Refiners members produce nearly all of the starch and corn syrup products. On this basis the corn refiners commercial shipments numbers are converted to dry weight to complete a mass balance, presented below.

Shipments of Corn Refining Products (Million lbs)

	Raw Input Quantity	Units	Source	Notes	Transformed Input Quantity	Units	Notes
CORN STARCH	5,556	Million lbs	(1)	I added the category "other glucose"	5,556	Million lbs dry wt.	Commercial wt. equals dry wt.
REFINERY PR	26,955	Million lbs	(1)	to account for the difference between			
OTHER GLUCO	8,375	Million lbs	(1)	refinery products, which includes	7,286	Million lbs dry wt.	Estimate at 85% solids.
HFCS 42	8,140	Million lbs	(1)	all of the syrups, and the totals for	5,779	Million lbs dry wt.	71% solids (3).
HFCS 55	10,441	Million lbs	(1)	HFCS.	8,039	Million lbs dry wt.	77% solids (3).
HFCS TOTAL	18,580	Million lbs	(1)				
TOTAL DOMES	32,511	Million lbs	(1)				
TOTAL EXPOR	739	Million lbs	(1)				
CORN OIL	799	Million lbs	(1)		799	Million lbs dry wt.	Estimated as commercial
G. FEED, C. OI	11,388	Million lbs	(1)		11,388	Million lbs dry wt.	weight equals dry weight
GLUTEN MEAL	2,031	Million lbs	(1)		2,031	Million lbs dry wt.	for these products.
STEEPWATER	458	Million lbs	(1)		229	Million lbs dry wt.	50% solids (7).
TOTAL SHIPME	47,926	Million lbs	(1)		41,107	Million lbs dry wt.	
WATER	-	Million lbs	(1)				

Notes: The wt. fraction of corn ending up in each product type is calculated based on the total consumption of corn by the wet corn milling industry, excluding corn grind for ethanol. Since this is based on dry weight, the difference between the total dry wt. and the wt. of corn used, gives the fraction of water in the corn, as received. Th 12.32% , is reasonable, so it is assumed that our calculations are relatively representative of the industry.

Total Wet Corn Mill Consumption of Corn

Year	Raw Input Quantity	Units	Source	Tranformed Quantity	Units
1987	723	Million Bushels	(3)	40,488	Million lbs
1988	757	Million Bushels	(3)	42,392	Million lbs
1989	766	Million Bushels	(3)	42,896	Million lbs

1990	791	Million Bushels	(3)	44,296	Million lbs
1991	811	Million Bushels	(3)	45,416	Million lbs
1992	839	Million Bushels	(3)	46,984	Million lbs
1993	865	Million Bushels	(3)	48,440	Million lbs
1994	905	Million Bushels	(3)	50,680	Million lbs

Conversion of Glucose Quantity into Relative Starch Quantity (to account for gain in mass from conversion process).

Chemical Gain	Raw Input Quantity	Source	Notes	
	4.10%	(8)	p. 572	
	5.80%	(3)	p. 70	
	11.11%	(7)	p. 219, Based on Stiochiometry	Average
We Use	4.95%		Average of two estimated values	

Total Sugars	Starch Equivalent	Units
21,105	20,109	Million lbs dry wt.

Comparison of Estimates of Theoretical Yield with Calculated Value from ERS and CRA Data.

Theoretical Yiel	Based on CRA Annual Prod. (lb)	ERS (3) (lb/bu)	%	CGA (6) (lb/bu)	%		NREL	
Corn In	46,883		56		56.00		579,078,355	
Starch	25,665	54.74%	31.5	56.25%	32.00	57.14%	345,601,903	59.68%
Oil (crude)	799	1.70%	1.55	2.77%	1.60	2.86%	23,338,321	4.03%
Gluten Feed	11,388	24.29%	13.5	24.11%	11.40	20.36%	73,552,278	12.70%
Gluten Meal	2,031	4.33%	2.65	4.73%	3.00	5.36%	25,092,049	4.33%
Steepwater	229	0.49% -	-					80.75%
Water	6,771	14.44%	6.8	12.14%	8.00	14.29%		
Total	40,112	85.56%	49.2	87.86%	48.00	85.71%		

Notes: The calculated yields are thus reasonable. Oil yield is lower than both the ERS and CGA theoretical values. This may be because some corn germ is sold to non-CRA refiners.

Material Balance Based on ERS and CRA Data

Annual Prod
Referenced to 1 Bushel

	Quantity	Units
Corn in	56	lb
Starch	30.66	lb
Oil	0.95	lb
Gluten Feed	13.60	lb
Gluten Meal	2.43	lb

If all starch were converted to Glucose, the yield would be:

	Quantity	Units
Corn in	56	lb
Glucose	32.17	lb
Oil	0.95	lb
Gluten Feed	13.60	lb
Gluten Meal	2.43	lb

Table 11 Sulfur Dioxide Use in Wet Corn Milling Industry

(1) U.S. EPA, AP-42, Section 9.9.7

(2) NREL Wet Corn Milling Model

Input		Quantity	Units	Source	Transformed Quantity
Sulfur Dioxide	low	0.06	lb/bu	(1)	0.06
	high	0.11		(1)	0.11
	average	0.00206	kg/kg corn	(2)	0.12
Sulfur Use					0.058

Notes: Sulfur dioxide use is converted to sulfur use using the ratio of weights of sulfur and sulfur dioxide.

Table 12 Ash Production from Coal Consumption

(1) Utility Data Institute. 1995. EEI Power Statistics Database.

(2) Babcock and Wilcox. 1992. Steam: Its Generation and Use, 40th Edition, S.C. Stulz and J.B. Kitto (eds.).

(3) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(4) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

There are two sources of ash in FBC systems, the naturally occuring ash in the coal, and ash formed from sulfur combining with the calcium in the bed. This reaction involves the conversion of calcium carbonate into calcium oxide ($CaCO_3 \rightarrow CaO$) and the subsequent formation of $CaSO_4$ from SO_2. Thus two moles of SO_2 are removed for every mole of Ca. In addition, CO_2 is emitted in the process.

		Source
Reactions	$CaCO_3 \rightarrow CaO(s) + CO_2(g)$	(2)
	$SO_2(g) + 1/2\ O_2(g) + CaO(s) \rightarrow CaSO_4(s)$	(2)

Ash Production from Coal Ash and Sulfur Removal

	Value	Units	Source	Notes
Coal Sulfur Con	2.50	Percent	Estimate	Reference (1) data indicates that the utility average sulfur content in Iowa, Indiana and Illinois in 1993 was about 1.5%.
Coal Ash Conte	7.70	Percent	(1)	
Coal Energy Co	22.276	Million Btu/ton	(3)	
Energy Consum	52,255	Btu/bu	Table 3	
Energy Consum	0.0023	tons coal/bu	Calculated	
Energy Consum	4.69	lb coal/bu	Calculated	
Ash From Coal	0.36	lb/bu	Calculated	
Ash From Sulfu	118.33	lb/ton coal	Calculated	
Ash From Sulfu	0.28	lb/bu	Calculated	
Total Ash	0.64	lb/bu	Calculated	

Carbon Dioxide Production from Limestone Consumption

	Quantity	Units	Notes:
Sulfur Removal	27.87	lb sulfur removed per ton c	Calculated as the total sulfur in Coal minus that emitted from emissions table above.
Carbon Dioxide	38.25	lb CO2 emitted per ton coa	Based on Stoichiometry
Carbon Dioxide	0.09	lb/bu	

EOF

		Table 5	Table 12	Table 7	Table 6	
		Energy Cons.	From CaCO3	WM Particula	Toxic Release	Total
ality poor.	NOx	4.78E-02	-	-	-	4.78E-02
ality poor.	SOx	5.19E-02	-	-	-	5.19E-02
ality poor.	PM-10	3.15E-02	-	-	-	3.15E-02
	Total Particula	-	-	5.42E-02	-	5.42E-02
ality poor.	CO	4.38E-02	-	-	-	4.38E-02
ality poor.	CO2	1.55E+01	8.97E-02	-	-	1.56E+01
ality poor.	Non-Methane	1.73E-04	-	-	-	1.73E-04
ality poor.	Methane	1.52E-04	-	-	-	1.52E-04
ality poor.	N2O	1.34E-02	-	-	-	1.34E-02
	HCL	-	-	-	3.57E-04	3.57E-04
	Ammonia	-	-	-	8.85E-05	8.85E-05
	Chlorine	-	-	-	3.91E-05	3.91E-05
	Sulfuric Acid	-	-	-	2.41E-05	2.41E-05

	Table 5	Table 12	Table 7	Table 6	
	Energy Con	From CaCO	WM Particu	Toxic Relea	Total
NOx	100.00%	-	-	-	100.00%
SOx	100.00%	-	-	-	100.00%
PM-10	100.00%	-	-	-	100.00%
Total Partic	-	-	100.00%	-	100.00%
CO	100.00%	-	-	-	100.00%
CO2	99.43%	0.57%	-	-	100.00%
Non-Methan	100.00%	-	-	-	100.00%
Methane	100.00%	-	-	-	100.00%
N2O	100.00%	-	-	-	100.00%
HCL	-	-	-	100.00%	100.00%
Ammonia	-	-	-	100.00%	100.00%
Chlorine	-	-	-	100.00%	100.00%
Sulfuric Aci	-	-	-	100.00%	100.00%

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conforms to other published estimates.

conforms to other published estimates.

conforms to other published estimates.

conforms to other published estimates.

conforms to other published estimates.

Toxic Releases for SIC 2046
All releases in lb

This table contains raw data on the release of toxic materials by the wet corn milling industry. The data was downloaded from the TRI database, as accessed through the RTK (Right To Know) network in June of 1995. Because of difficulty in downloading a suitably formatted electronic data set, the information was instead compiled from a hard copy printout. The data were input to this spreadsheet and extensively checked, however there is always the possiblity of error.

The raw data include information on a fairly large number of pollutants. Seven of the facilities listed here provided information on the route from which each toxic release was generated. Responses by each facility were consistent, and indicate that most of the toxic material released is associated with processes such as corn starch modification, ion exchange resin regeneration, and ethanol production. Since these processes are not necessary to the production of glucose, these emissions are not assigned to glucose manufacture. The toxics that are associated with glucose manufacture are ammonia, HCL, chlorine, and sulfuric acid. The list below gives a brief description of how each of the toxic chemicals associated with wet corn milling are used.

Hydrochloric Acid	Used for ion exchange regeneration, pH adjustment, and in some cases for conversion of starch to glucose.
Ammonia	Used as a nutrient (nitrogen source) in either wastewater treatment or for fermentation.
Sulfuric Acid	Used as a pH adjuster and for ion exchange regeneration.
Chlorine	Used to treat well water or cooling water. Some chlorine emissions may be associated with coal combustion emissions to the stack.
Ammonium Sulfate	Probably also associated with use of ammonia as nutrient.
Ethylene Oxide	Used to modify starches
Ethylene Glycol	From the reaction of ethylene oxide with water.
Propylene Oxide	Used to modify starches
Propylene Glycol	From the reaction of propylene oxide with water.
Phosphoric Acid	Used for ion exchange regeneration and as nutrient in wastewater.
Methanol	Byproduct of ethanol production?
Acetaldehyde	?
Sodium Sulfate	?
Sodium Hydroxide	Used for pH control.
Freon 113	Refrigerant.
Nitric Acid	?
Peracetic Acid	Used to modify starches and in production of HFCS.
Cyclohexane	Dehydrating agent in the production of ethanol.
Lead Compounds	Emissions from coal combustion.
Nickel Compounds	Emissions from coal combustion.
Selenium	Emissions from coal combustion.
Vanadium	Emissions from coal combustion.
Barium	Emissions from coal combustion.
Manganese	Emissions from coal combustion.
Styrene	?
Butadiene	?
Ammonium Nitrate	Probably also associated with use of ammonia as nutrient.

Methanol	Byproduct of ethanol production?
Epichlorohydrin	Used to modify starches.
Dibromoterafluoroehtane	Refrigerant.
Bromotrifluoromethane	Refrigerant.
Trichlorofluoromethane	Refrigerant.
Dichlorodifluoromethane	Refrigerant.
Hydrogen Fluoride	?
Toluene	?
Benzene	?
N-Butyl Alcohol	?
Vinyl Acetate	?
Xylene	?

This set of pollutants is associated with the large ADM facilities which produce ethanol. I am assuming that they are thus associated with processes other than the basic glucose manufacture.

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

		Ammonia				HCL				Chlorine				Sulfuric Acid			
Year	Grind (million bu)	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land
1987	1104	416721	1000	50250	50459	16578	20996	0	4750	1,500	0	250	0	1,002	538	13	0

1988	1160	68669	3686	161420	250	11331	7870	0	750	3,670	10,252	250	0	1,751	1,013	0	0
1989	1221	81151	5052	710368	1450	16055	32073	11	1011	7,172	12,000	250	0	1,504	791	0	0
1990	1221	19706	8332	776472	6865	14241	34203	5	1000	2,755	10	1,277	0	1,032	59	755	0
1991	1318	18264	5384	427024	13576	12987	1261725	600	27000	2,501	159,896	11,176	0	268	61	0	0
1992	1375	16252	4437	266877	0	7214	955691	250	200	1,267	155,055	1,433	0	272	104,443	0	0
1993	1413	71687	1725	56649	0	12010	977391	0	15910	2,487	4,887	1	1	532	120,459	5	1,182
		692450	29616	2449060	72600	90416	3289949	866	50621	21,352	342,100	14,637	1	6,361	227,364	773	1,182
		692450	29616	2449060	72600	90416	3289949	866	50621	21,352	342,100	14,637	1	6,361	227,364	773	1,182

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)
Based on total corn grind for starch products, byproducts, and ethanol production.

		Ammonia				HCL				Chlorine				Sulfuric Acid			
Year	Grind (million bu)	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land	Fug Air	Stack Air	Water	Land
1987	1104	0.000377465	9.1E-07	4.6E-05	4.6E-05	1.5E-05	1.9E-05	0	4.3E-06	1.36E-06	0.00E+00	2.26E-07	0.00E+00	9.08E-07	4.87E-07	1.18E-08	0.00E+00
1988	1160	5.91974E-05	3.2E-06	0.00014	2.2E-07	9.8E-06	6.8E-06	0	6.47E-07	3.16E-06	8.84E-06	2.16E-07	0.00E+00	1.51E-06	8.73E-07	0.00E+00	0.00E+00
1989	1221	6.64627E-05	4.1E-06	0.00058	1.2E-06	1.3E-05	2.6E-05	9E-09	8.28E-07	5.87E-06	9.83E-06	2.05E-07	0.00E+00	1.23E-06	6.48E-07	0.00E+00	0.00E+00
1990	1221	1.61392E-05	6.8E-06	0.00064	5.6E-06	1.2E-05	2.8E-05	4.1E-09	8.19E-07	2.26E-06	8.19E-09	1.05E-06	0.00E+00	8.45E-07	4.83E-08	6.18E-07	0.00E+00
1991	1318	1.38574E-05	4.1E-06	0.00032	1E-05	9.9E-06	0.00096	4.6E-07	2.05E-05	1.90E-06	1.21E-04	8.48E-06	0.00E+00	2.03E-07	4.63E-08	0.00E+00	0.00E+00
1992	1375	1.18196E-05	3.2E-06	0.00019	0	5.2E-06	0.0007	1.8E-07	1.5E-07	9.21E-07	1.13E-04	1.04E-06	0.00E+00	1.98E-07	7.60E-05	0.00E+00	0.00E+00
1993	1413	5.07339E-05	1.2E-06	4E-05	0	8.5E-06	0.00069	0	1.1E-05	1.76E-06	3.46E-06	7.08E-10	7.08E-10	3.77E-07	8.53E-05	3.54E-09	8.37E-07
Average		8.50964E-05	3.4E-06	0.00028	9E-06	1E-05	0.00035	9.3E-08	5.5E-06	2.46E-06	3.66E-05	1.6E-06	1.01E-10	7.53E-07	2.33E-05	9.05E-08	1.2E-07

Plant Level Data
Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

				Fugitive Air																
Plant	City	Year		Hydrochlor	Ammonia	Ammonium	Chlorine	Sulfuric Ac	Ethylene O	Ethylene G	Propylene	Propylene	Phosphoric	Methanol	Acetaldehy	Epichloroh	Sodium Su	Sodium Hy	Dibromoter	Bromotriflu
American Maize Products	Decatur		1987	250	0		0											0		
			1988	250	0		0											0		
			1989	250	0		0													
			1990	250	0		0													
			1991	250	0		0													
			1992	250	0		0													
			1993	250	0		0													
A. E. Staley Mfg. Co.	Van Buren		1987		250									77000						
			1988		250									276,916				0		
			1989		250									120,912						
			1990		250			0			250		0	110,000						
			1991		200								0	42,000						
			1992		200								0	25,000						
			1993		5			5			250		0	22,900						
CPC International Inc.	Stockton		1987	750	5000	0											0	250		
			1988	750	1900	0	250	250										250		
			1989	750	2100	0	250	250							0					
			1990	750	0			5							1000					
			1991	750				5							1000					
			1992	750				5					0		1000					
			1993	750				5							1000					
A.E. Staley Mfg. Co.	Monte Vista		1987		0													0		
			1988	250														0		
			1989	250																
			1990	250	0															
			1991	5																
			1992	5																
			1993	5																

ADM Corn Processing	Clinton	1987	750	250		250	250	250								250		
		1988	750	250		250	250	250								250		
		1989	750	250	250	250	250	250						250				
		1990	750	250	250	250	250	250						250				
		1991	250	250	0	0	0	5						5			0	610
		1992	250		0	0	0	5				0		5			7500	
		1993	250	250	0	0	250	5						5				
Hubinger Co.	Keokuk	1987	250	750						0				0		0		
		1988	250	750		750				0				0		0		
		1989	250	750		250				0				0				
		1990	250	750		259	250			0				0				
		1991	52	12		0	0			0				0				
		1992	250	250		0	0			0				0				
		1993	250				0			0				0				
ADM Corn Processing	Cedar Rapids	1987																
		1988	250	250		250	250									250		
		1989	250	250		250	250											
		1990	250	250		250	250											
		1991	250	250		250	250											
		1992	250	250		250	250	60	0									
		1993	1204	250		250	250	84	0									
Cargill Inc.	Cedar Rapids	1987	2152												0	0		
		1988	820				0	26	0							0		
		1989	818					39	0									
		1990	750	0				250	0									
		1991	809					25	0									
		1992	1204															
		1993	1204					84										
Penford Products Co.	Cedar Rapids	1987	6000			250		750	0							750		
		1988	750			250		16600	0	250						0		
		1989	750			250		750	0									
		1990	750	0		250		750	0									
		1991	5			5		250	0									
		1992	250			5		250	0									
		1993	250			5		250	0	250								
Cargill Inc.	Eddyville	1987	987		0	0	0								0	0		
		1988	1300	20000	0	170	0									0		
		1989	1400	43000	0	170												
		1990	1547	14006		1229	0											
		1991	1432	6778		1229	0											
		1992		4536			0				0							
		1993	1430	5138		1221	0				0							
A. E. Staley Mfg. Co.(Eldarado	Decatur	1987	250	2600		250	0	250	0	8000					250	0		
		1988	250	1550		750	250	250	250	8000			20000			250		
		1989	250	1550		5000	250	250	250	7000			18445					
		1990	250	750		250	5	250	5	750								
		1991	250	250		5	5	250	5	250								
		1992	250	250		5	5	5	5	250								
		1993	250	250		10	5	5	5	250								
National Starch & Chemical Co	Indianapolis	1987	205			0	1			27					0	62		
		1988	55			0				30						12		
		1989	156			2	3			29								
		1990	145	0		2	6			20828								
		1991	134			2	3			30								
		1992	133			2	2			17								
		1993	100			1	2			31								
A. E. Staley Mfg. Co. (Sagamo	Lafayette	1987	250	250		250	0			250	0				0			
		1988	250			250	0			250	0							
		1989	250	250		250	0				0							
		1990	250	250		5	0			250	0							

		1991	250	250		5							
		1992	250	250		250			250				
		1993	250	250		250			250				
Minnesota Corn Processors	Marshall	1987											
		1988	0	0		0	0						
		1989	0	0		0	0						
		1990	0	0		0	0						
		1991	250			0	0						
		1992	0			0	0						
		1993	0			0	0						
National Starch & Chemical Co	Kansas City	1987	22	5			1		4	0		0	10
		1988	6	2			1		4	1			11
		1989	12	1			1		1	0			
		1990	2	1			1		5	0			
		1991	2	0			0		8	0			
		1992	2	1			0		6	0			
		1993	2	1			0		314	0			
Minnesota Corn Processors	Columbus	1987											
		1988											
		1989											
		1990		0									
		1991											
		1992				0	0			0			
		1993	0			0	0						
ADM Corn Processing	Montezuma	1987	0	0		0	0						0
		1988	0				0						
		1989					0						
		1990		0			5						
		1991											
		1992											
		1993											
Cargill Inc.	Dayton	1987	1702	5423			0					0	0
		1988	1700				0						0
		1989	3600	0			0						
		1990	3600	0			0						
		1991	3600	0			0						
		1992	1260	0			0						
		1993	1260	0			0						
A. E. Staley Mfg. Co.	Loudon	1987	250	250		250	250					0	0
		1988	250	4967		250	250						0
		1989											
		1990	250	250			250						
		1991	5	19			0						
		1992	5	15			0						
		1993	5	43			5						
Cargill Inc.	Memphis	1987	1710	401693	0		0					0	0
		1988	2200	38000	0		0						0
		1989	5069	32000	0		0						
		1990	2942	0			0						
		1991	2943	0			0						
		1992	1100	0			0						
		1993	1100	0			0						
ADM Corn Processing	Decatur	1987	250	250		250	250						250
		1988	250	250		250	250						250
		1989	250	250		250	250				0		
		1990	250	2449		5	5				0		
		1991	750	10000		750	5				0		
		1992		10000		750	5						
		1993	750	65000		750	5						
American Maize Products	Hammond	1987	0	0		0		250	250			0	0

Plant	City	Year	Hydrochlor	Ammonia	Ammonium	Chlorine	Sulfuric Ac	Ethylene O	Ethylene G	Propylene	Propylene	Phosphoric	Methanol	Sodium Su	Sodium Hy	Hydrogen F	Acetaldehy	Epichloroh	Dibromotet
		1988	0	250		0		250		250									
		1989	0	250		0		250		250									
		1990	5	250		5		250		250									
		1991		5		5		250		5									
		1992	5	250		5				1362									
		1993	1700	250						1800									
American Maize Products	Dimmitt	1987																	
		1988	250	250		250											250		
		1989	250	250		250													
		1990	250	250		250													
		1991	250	250		250													
		1992	250	250															
		1993	250	250															
CPC	Winston-Salem	1987	800				250									0	250		
		1988	750				250										250		
		1989	750				250												
		1990	750	0			5												
		1991	750																
		1992	750				5												
		1993	750				5												
Total		1987	16,578	416,721	0	1,500	1,002	1,500	0	8,531	0	0	77,000	0	0	250	1,822	0	0
		1988	11,331	68,669	0	3,670	1,751	17,376	250	8,784	0	1	276,916	20,000	0	0	1,773	0	0
		1989	16,055	81,151	250	7,172	1,504	1,539	250	7,280	0	0	120,912	18,445	250	0	0	0	0
		1990	14,241	19,706	250	2,755	1,032	1,750	5	22,333	0	0	110,000	1,000	250	0	0	0	0
		1991	12,987	18,264	0	2,501	268	780	5	293	0	0	42,000	1,000	5	0	0	0	610
		1992	7,214	16,252	0	1,267	272	320	5	1,885	0	0	25,000	1,000	5	0	0	7,500	0
		1993	12,010	71,687	0	2,487	532	428	5	3,145	0	0	22,900	1,000	5	0	0	0	0
Average			12,917	98,921	71	3,050	909	3,385	74	7,464	0	0	96,390	6,064	74	36	514	1,071	87

Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Stack Air

Plant	City	Year	Hydrochlor	Ammonia	Ammonium	Chlorine	Sulfuric Ac	Ethylene O	Ethylene G	Propylene	Propylene	Phosphoric	Methanol	Sodium Su	Sodium Hy	Hydrogen F	Acetaldehy	Epichloroh	Dibromotet
American Maize Products	Decatur	1987	750												0				
		1988	0												0				
		1989	0																
		1990	5																
		1991	250																
		1992	250																
		1993	250																
A. E. Staley Mfg. Co.	Van Buren	1987		250									215000		0				
		1988		250									200,000						
		1989		250									179,599						
		1990		250			0			250		0	200,178						
		1991		0								0	78,000						
		1992		0								0	30,000						
		1993		0			5			19		0	4,500						
CPC International Inc.	Stockton	1987	250	0	0									0	250				
		1988	250	0	0	10,000	250								250			250	
		1989	250	0	0	12000											0		
		1990	27				5										550		
		1991	250				5										750		
		1992	250				5										750		
		1993	250				5										750		
A. E. Staley Mfg. Co.	Monte Vista	1987													0				
		1988	250												0				
		1989	250																

		1990	250																
		1991	250																
		1992	5																
		1993	5																
ADM Corn Processing	Clinton	1987	250		0	0	0	0							0				
		1988	250	0		0	0	0							0				
		1989	250	0	250	0	0	0											
		1990	250	0	250	0	0	0										250	
		1991	1200000	780	0	0	0	250								0		0	6300
		1992	740000		0		0	250					5			72000		0	0
		1993	740000		0	0	0	250								62000		5	
Hubinger Co.	Keokuk	1987	0	0						0					0			0	
		1988	0	0		0				0					0			0	
		1989	0	0		0					0							0	
		1990	0	0		0	0			0								0	
		1991	0	0		24883	0			0						0		0	
		1992	5	5		21910	0				0							0	
		1993	5				0			0								0	
ADM Corn Processing	Cedar Rapids	1987																	
		1988	0	0		0	0								0				
		1989	0	0		0	0												
		1990	0	0		0	0												
		1991	0	0		129,940	0									0			
		1992	0	0		132,640	0	0	0										
		1993	250	0		250	0	250											
Cargill Inc.	Cedar Rapids	1987	662	0										0	0				
		1988	900				0	0	0						0				
		1989	818					0	0										
		1990	750					0	0										
		1991	2726					0	0							0			
		1992	30127																
		1993	28342					0	0										
Penford Products Co.	Cedar Rapids	1987	250			0		250	0						0				
		1988	250			0		250	0	250					0				
		1989	250			0		750	0										
		1990	250			0		750	0										
		1991	5			0		750	0							0			
		1992	250			250		250	0										
		1993	250	250				250	0										
Cargill Inc.	Eddyville	1987	83		0	0								0	0				
		1988	80	0	0	0	0								0				
		1989	300	0	0	0													
		1990	145		0	0	0												
		1991	8999	0		4323	0									0			
		1992		0			11180					0							
		1993	9258	0		4635	11000					0							
A. E. Staley Co.(eldorado)	Decatur	1987	11200	250		0	0	2909	0	50000				0	0		35000		
		1988	750	750		250	250	3227	250	5600					250				
		1989	1200	750		0	250	3760	250	3500							35000		
		1990	1182	1780		5	5	1513	5	250									
		1991	750	630		250	5	1920	5	3960						0			
		1992	750	750		250	5	217	5	2160									
		1993	619	720		1	5	2	5	2100									
National Starch & Chemical Co	Indianapolis	1987	1209			0	25			19335				0	88				
		1988	1349			2				20733					46				
		1989	1052			0	26			19898									
		1990	1426			0	20			20828									
		1991	1036			0	27			20219						0			
		1992	466			0	18			13337									
		1993	417			1	29			107711									

A. E. Staley Mfg. Co. (Sagamo	Lafayette	1987	0	0		0		71576	0		129		
		1988	11			0	0	51259	0				
		1989	11	250		0	0		0				
		1990	250	0		0	0	33961	0				
		1991	250					31819					0
		1992	250					24985					
		1993	250					29250					
Minnesota Corn Processors	Marshall	1987											
		1988	0	0		0	0						
		1989	0	0		0	0						
		1990	0	0		0	0						
		1991	0			0	0						0
		1992	250			0	0						
		1993	250			0	0						
National Starch & Chemical Co	Kansas City	1987	404	0			13	5594	0		0	9	
		1988	200	1936			13	14574	1			7	
		1989	442	2312			15	5376	3				
		1990	596	5797			14	7219	3				
		1991	868	3219			14	8037	3				0
		1992	1027	2927			15	9254	3				
		1993	2	0			0	0	3				
Minnesota Corn Processors	Columbus	1987											
		1988											
		1989											
		1990											
		1991											0
		1992				0	5		5				
		1993	250			0	5						
ADM Corn Processing	Montezuma	1987	0	0		0	0					0	
		1988	0				0						
		1989					0						
		1990					0						
		1991											0
		1992											
		1993											
Cargill Inc.	Dayton	1987	232	0			0				0	0	
		1988	330				0					0	
		1989	200	0			0						
		1990	70	0			0						
		1991	7000	0			0						0
		1992	76580	0			83000						
		1993	89350	0			98200						
A. E. Staley Mfg. Co.	Loudon	1987	750	0		0	0				0	0	
		1988	750	0		0	0					0	
		1989											
		1990	250	5			5						
		1991	51	5			5						0
		1992	40	5			5						
		1993	43	5			5						
Cargill Inc.	Memphis	1987	456	0	0		0				0	0	
		1988	1000	0	0		0					0	
		1989	1300	740	0		0						
		1990	1247	0			0						
		1991	5848	0			0						0
		1992	69200	0			10200						
		1993	75600	0			11200						
ADM Corn Processing	Decatur	1987	250	250		0	250					250	
		1988	250	250		0	250					250	
		1989	250	250		0	250			250			
		1990	250		250	0	5			250			

		1991	250	250		0	5						250			0			0
		1992		250		0	5												0
		1993	250	250															
American Maize Products	Hammond	1987	250	250		0		44852		58667				250	0				
		1988	250	250		0		750		1133									
		1989	250	250		0		65600		96400									
		1990	5	250		5		65991		19377									
		1991	3942	250		250		5857		690						0			
		1992	3991	250		5				34886									
		1993	1500	250						42000									
American Maize Products	Dimmitt	1987													250				
		1988	250	250															
		1989	250	250															
		1990	250	250															
		1991	250	250		250										0			
		1992	250	250															
		1993	250	250															
CPC	Winston-Salem	1987	4000				250								250				
		1988	750				250								250				
		1989	25000				250												
		1990	27000				5												
		1991	29000													0			
		1992	32000				5												
		1993	30000				5												
Total		1987	20,996	1,000	0	0	538	48,011	0	205,172	0	0	215,000	379	1,097	0	35,000	0	0
		1988	7,870	3,686	0	10,252	1,013	4,227	250	93,549	0	1	200,000	0	1,053	0	0	250	0
		1989	32,073	5,052	250	12,000	791	70,110	250	125,174	0	3	179,849	0	0	0	35,000	0	0
		1990	34,203	8,332	500	10	59	68,254	5	81,885	0	3	200,428	0	0	0	550	250	0
		1991	########	5,384	0	159,896	61	8,777	5	64,725	0	3	78,250	0	0	0	750	0	6,300
		1992	955,691	4,437	0	155,055	104,443	717	5	84,622	0	8	30,005	0	0	72,000	750	0	0
		1993	977,391	1,725	0	4,887	120,459	752	5	181,080	0	3	4,500	0	0	62,000	750	5	0
Average			469,993	4,231	107	48,871	32,481	28,693	74	119,458	0	3	129,719	54	307	19,143	10,400	72	900

Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Water

Plant	City	Year		Hydrochlor	Ammonia	Ammonium	Chlorine	Sulfuric Ac	Ethylene O	Ethylene G	Propylene	Propylene	Phosphoric	Methanol	Sodium Su	Sodium Hy	Hydrogen F	Acetaldehy	Epichloroh	Dibromotet
American Maize Products	Decatur		1987	0												0				
			1988	0												0				
			1989	0																
			1990	0																
			1991	0																
			1992	0																
			1993	0																
A. E. Staley Mfg. Co.	Van Buren		1987	0	0	0								0	0	0				
			1988	0	0	0	0	0						0		0				
			1989	0	0	0	0							0				0		
			1990		0			0			0		0	0						
			1991		0								0	250						
			1992		22								0	5						
			1993	0	82			5			5		250	5						
CPC International Inc.	Stockton		1987	0	0	0									0	0				
			1988	0	0	0	0	0								0		0		
			1989	0	0	0	0													
			1990																	
			1991																	
			1992																	

		1993	0																
A.E. Staley	Monte Vista	1987																	
		1988																	
		1989																	
		1990																	
		1991																	
		1992																	
		1993																	
ADM Corn Processing	Clinton	1987	0	50,000		250	0	0							0				
		1988	0	90000		250	0	0							0				
		1989	0	90000	0	250	0	0										0	
		1990	5	90000	0	250	5	0										0	
		1991	0	870	0	0	0	0								0		0	0
		1992	0		0	0	0	0					0			0		0	0
		1993	0		0	0	0	0								0		0	
Hubinger Co.	Keokuk	1987	0							0					0			0	
		1988	0	0		0				0	0				0			0	
		1989	0	30000		0				0								0	
		1990	0	30000		0	0			0								0	
		1991	0	72000		0	0			0								0	
		1992	0	105,485		0	0				0							0	
		1993	0				0			0								0	
ADM Corn Processing	Cedar Rapids	1987																	
		1988	0	0		0	0							0					
		1989	0	0		0	0												
		1990	0	0		0	0												
		1991	0	0		0	0												
		1992	250	250		0		0	0										
		1993	0	0		0		0											
Cargill Inc.	Cedar Rapids	1987	0				0							0	0				
		1988	0				0	0	0						0				
		1989	0					0	0										
		1990	0					0	0										
		1991	600					0	0										
		1992																	
		1993	0					0	0										
Penford Products Co.	Cedar Rapids	1987	0			0		0	0						0				
		1988	0			0		34800	0	0					0				
		1989	0			0		0	0										
		1990	0			0		0	0										
		1991	0			0		0	0										
		1992	0			250	0	0	0										
		1993	0			0		0	0										
Cargill Inc.	Eddyville	1987	0		456225	0								2907968	0				
		1988	0	7900	440000	0	0								0				
		1989	0	515000	70000	0													
		1990	0	547916		0	0												
		1991	0	237695		0	0												
		1992		73164			0					0							
		1993	0	43366		0	0					0							
A. E. Staley Mfg. Co.(eldorado	Decatur	1987	0	0		0	0	2909	0	0				0	0		0		
		1988	0	0		0	0	0	0	0					0				
		1989	0	0		0	0	0	250	0							0		
		1990	0	0		0	750	0	0	0									
		1991	0	0		0	0	0	0		0								
		1992	0	0		0	0	0	0	0									
		1993	0	0		0	0	0	0	0									
National Starch & Chemical Co	Indianapolis	1987	0			0	0			0				0	0				
		1988	0			0				0					0				
		1989	0			0	0			0									

		1990	0			0	0	0			
		1991	0			0	0	0			
		1992	0			0	0	0			
		1993	0			1	0	0			
A. E. Staley Mfg. Co. (Sagamo	Lafayette	1987	0	0		0	0	0	0	0	
		1988	0			0	0	0	0		
		1989	11	0		0	0		0		
		1990	0	0		0	0	0	0		
		1991									
		1992									
		1993	0								
Minnesota Corn Processors	Marshall	1987									
		1988	0	0		0	0				
		1989	0	0		0	0				
		1990	0	0		0	0				
		1991	0			0	0				
		1992	0			0	0				
		1993	0			0	0				
National Starch & Chemical Co	Kansas City	1987	0	0			13	0	0	0	0
		1988	0	0			0	0	0		0
		1989	0	0			0	0	0		
		1990	0	0			0	0	0		
		1991	0	0			0	0	0		
		1992	0	0			0	0	0		
		1993	0	0			0	0	0		
Minnesota Corn Processors	Columbus	1987									
		1988									
		1989									
		1990									
		1991									
		1992				0	0		0		
		1993	0			0	0				
ADM Corn Processing	Montezuma	1987	0	0		0	0				0
		1988	0				0				
		1989					0				
		1990					0				
		1991									
		1992									
		1993	0								
Cargill Inc.	Dayton	1987	0	0			0			0	0
		1988	0				0				0
		1989	0	0			0				
		1990	0	0			0				
		1991	0	0			0				
		1992	0	0			0				
		1993	0	0			0				
A.E. Staley Mfg. Co.	Loudon	1987	0	0		0	0			0	0
		1988	0	0		0	0				0
		1989									
		1990	0	0			0				
		1991	0	0			0				
		1992	0	0			0				
		1993	0	13201			0				
Cargill Inc.	Memphis	1987	0	0	0		0			0	0
		1988	0	0	0		0				0
		1989	0	0	0		0				
		1990	0	0			0				
		1991	0	0			0				
		1992	0	0			0				
		1993	0	0			0				0

ADM Corn Processing	Decatur	1987	0	0		0	0								0				
		1988	0	250		0	0								0				
		1989	0	0		0	0						0						
		1990	0	0		0	0						0						
		1991	0	0		0	0						0						0
		1992		0		0	0												0
		1993	0																
American Maize Products	Hammond	1987	0	250		0		250		250				1221456	3328388				
		1988	0	63270		0		0		0									
		1989	0	75368		0		0		0									
		1990	0	108556		1027		0		0									
		1991	0	116459		11176		0		0									
		1992	0	87956		1183				0									
		1993	0	0						0									
American Maize	Dimmitt	1987																	
		1988																	
		1989																	
		1990																	
		1991																	
		1992																	
CPC	Winston-Salem	1993	0																
		1987																	
		1988																	
		1989																	
		1990																	
		1991																	
		1992																	
		1993	0																
Total		1987	0	50,250	456,225	250	13	3,159	0	250	0	0	0	########	########	0	0	0	0
		1988	0	161,420	440,000	250	0	34,800	0	0	0	0	0	0	0	0	0	0	0
		1989	11	710,368	70,000	250	0	0	250	0	0	0	0	0	0	0	0	0	0
		1990	5	776,472	0	1,277	755	0	0	0	0	0	0	0	0	0	0	0	0
		1991	600	427,024	0	11,176	0	0	0	0	0	0	250	0	0	0	0	0	0
		1992	250	266,877	0	1,433	0	0	0	0	0	0	5	0	0	0	0	0	0
		1993	0	56,649	0	1	5	0	0	5	0	250	5	0	0	0	0	0	0

Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Land

Plant	City	Year	Hydrochlor	Ammonia	Ammonium	Chlorine	Sulfuric Ac	Ethylene O	Ethylene G	Propylene	Sodium Hy	Styrene
American Maize Products	Decatur	1987	0								0	
		1988	0								0	
		1989	0									
		1990	0									
		1991	0									
		1992	0									
		1993	0									
A. E. Staley Mfg. Co.	Van Buren	1987	0	0	0						0	
		1988	0	0	0	0	0				0	
		1989	0	0	0	0						
		1990		0			0			0		
		1991		0								
		1992		0								
		1993		0			0			0		
CPC Internationl Inc.	Stockton	1987	0	0	0						0	
		1988	0	0	0	0	0				0	
		1989	0	0	0	0	0					
		1990										
		1991										

		1992										
		1993										
A.E. Staley	Monte Vista	1987	250									
		1988									250	
		1989	250									
		1990	250									
		1991										
		1992										
		1993										
ADM Corn Processing	Clinton	1987	0	0		0	0	0			0	
		1988	0	0		0	0	0			0	
		1989	0	0	0	0	0	0				
		1990	0	0	0	0	0	0				
		1991	0	0	0	0	0	0				
		1992	0		0	0	0	0				
		1993	7955		0	0	0	0				5
Hubinger Co.	Keokuk	1987	0							0	0	
		1988	0	0		0				0	0	
		1989	0	0		0				0		
		1990	0	0		0	0			0		
		1991	0	0		0	0			0		
		1992	0	0		0	0			0		
		1993	0				0			0		
ADM Corn Processing	Cedar Rapids	1987										
		1988	0	0		0	0				0	
		1989	0	0		0	0					
		1990	0	0		0	0					
		1991	0	0		0						
		1992	0	0				0	0			
		1993		0		0						
Cargill Inc.	Cedar Rapids	1987	0								0	
		1988	0				0	0	0		0	
		1989	0					0	0			
		1990	0				0	0	0			
		1991	0					0	0			
		1992										
		1993	0					0	0			
Penford Products Co.	Cedar Rapids	1987	0			0		0	0		0	
		1988	750			0		750	0	250	250	
		1989	750			0		0	250			
		1990	750			0		0	250			5
		1991	27000			0		0	250			0
		1992	200			0	0	0	5			0
		1993	7955			0		0	0			5
Cargill Inc.	Eddyville	1987	0	0	0	0					0	
		1988	0		3300	0	0				0	
		1989	0	1200	0	0						
		1990	0	6615		0	0					
		1991	0	8576		0	0					
		1992		0			0					
		1993	0	0		0	0					
A. E. Staley Mfg. Co.(eldorado	Decatur	1987	4500	0		0	0	0	0	0	0	
		1988	0	0		0	0	0	0	0	0	
		1989	0	0		0	0	0	0	0		
		1990	0	0		0	0	0	0	0		
		1991	0	0		0	0	0	0	0		
		1992	0	0		0	0	0	0	0		
		1993	0	0		0	0	0	0	0		
National Starch & Chemical Co	Indianapolis	1987	0			0	0			0	0	
		1988	0			0				0	0	

		1989	0			0	0	0	
		1990	0			0	0	0	
		1991	0			0	0	0	
		1992	0			0	0	0	
		1993	0			1	0	0	
A . E. Staley Mfg. Co. (Sagamo	Layfette	1987	0	0		0	0	0	
		1988	0			0	0	0	
		1989	11	0		0	0		
		1990	0			0		0	
		1991		0			0		
		1992							
		1993							
Minnesota Corn Processors	Marshall	1987							
		1988	0	0		0	0		
		1989	0	0			0		
		1990	0	0		0	0		
		1991	0			0	0		
		1992	0			0	0		
		1993	0				1182		
National Starch & Chemical Co	Kansas City .	1987	0	0			0	0	0
		1988	0	0			0	0	0
		1989	0	0			0	0	
		1990	0	0			0	0	
		1991	0	0			0	0	
		1992	0	0			0	0	
		1993	0	0			0	0	
Minnesota Corn Processors	Columbus	1987							
		1988							
		1989							
		1990							
		1991							
		1992				0	0		
		1993	0			0	0		
ADM Corn Processing	Montezuma	1987	0	0		0	0		0
		1988	0				0		
		1989					0		
		1990					0		
		1991							
		1992							
		1993							
Cargill Inc.	Dayton	1987	0	0			0		0
		1988	0				0		0
		1989	0	0			0		
		1990	0	0			0		
		1991	0	0			0		
		1992	0	0			0		
		1993	0	0			0		
A. E. Staley Mfg. Co.	Loudon	1987	0	0		0	0		0
		1988	0	0		0	0		0
		1989							
		1990	0	0			0		
		1991	0	0			0		
		1992	0	0			0		
		1993	0	0			0		
Cargill Inc.	Memphis	1987	0	0	0		0		0
		1988	0	0	0		0		0
		1989	0	0	0		0		
		1990	0	0			0		
		1991	0	0			0		
		1992	0	0			0		

		1993	0	0			0					
ADM Corn Processing	Decatur	1987	0	250		0	0				0	
		1988	0	250		0	0				0	
		1989	0	250		0	0					
		1990	0	250		0	0					
		1991	0	5000		0	0					
		1992		0		0	0					
		1993										
American Maize Products	Hammond	1987		50209		0		0		0	0	
		1988	0	0		0		0		0	0	
		1989	0	0		0		0		0		
		1990	0	0		0		0		0		
		1991	0	0		0		0		0		
		1992	0	0		0				0		
		1993	0	0						0		
American Maize Products	Dimmitt	1987										
		1988										
		1989										
		1990										
		1991										
		1992										
		1993										
CPC	Winston-Salem	1987										
		1988										
		1989										
		1990										
		1991										
		1992										
		1993										
Total		1987	4,750	50,459	0	0	0	0	0	0	0	0
		1988	750	250	3,300	0	0	750	0	250	500	0
		1989	1,011	1,450	0	0	0	0	250	0	0	0
		1990	1,000	6,865	0	0	0	0	250	0	0	5
		1991	27,000	13,576	0	0	0	0	250	0	0	0
		1992	200	0	0	0	0	0	5	0	0	0
		1993	15,910	0	0	1	1,182	0	0	0	0	10
Average			7,232	10,371	471	0	169	107	108	36	71	2

Hydrogen F	Freon 113	Peracetic A	Cyclohexan	Xylene	Lead Comp	Nickel Com	Selenium	Vanadium	Barium	Manganese	Nitric Acid	Styrene	Butadiene	Ammonium	N-Butyl Alc	Vinyl Aceta	Benzene	Trichloroflu	Toluene	Dichlorodifluoromethane

				250												
0																
0																
0																
	22000	0														
	96800	0														
	74800	0														
	74800	0	0	0												
	30800	0	10		0	0										
	24200	0	0		0	0	0	0	0	0						
		0	0		0		0	0	0	0						
											250					
											250					
												250	250			
												5	5			
											5	5	250			
												5	250			
											0			0		
											0			0		
											0			0		
											0					
						0									250	250
	40000					0										3200
						0										250
						0										
						0										
						0										
						0										

40000			250		
162400					
102445					
178140	0	0		23800	113050
	0	0		24200	80600
	0	0		8800	46200

0
0

40613
110000

0	62,000	0	0	250	0	0	0	0	0	0	0	0	0	0	250	250	250	0	0	0
0	299,200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,200	0	0	0	0
0	177,245	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0	0	0
0	252,940	0	0	0	0	0	0	0	0	0	250	250	250	0	0	0	0	0	0	0
0	30,800	0	10	0	0	0	0	0	0	0	250	5	5	0	0	0	0	23,800	0	113,050
0	24,200	0	0	0	0	0	0	0	0	0	5	5	250	0	0	0	0	24,200	40,613	80,600
0	0	0	0	0	0	0	0	0	0	0	0	5	250	0	0	0	0	8,800	110,000	46,200
0	120,912	0	1	36	0	0	0	0	0	0	72	38	108	0	36	529	36	8,114	21,516	34,264

Bromotriflu Freon 113 Peracetic ACyclohexanXylene Lead CompNickel ComSelenium Vanadium Barium ManganeseNitric Acid Styrene Butadiene AmmoniumVinyl AcetaBenzene trichloroflurToluene

				0												
120																
	0	0														
	0	0														
	0	0														
	0	0	250	0												
	0	0	0		35280	43084										
	0	0	5		38414	51,760	960	5850	22192	9137						
		0	5		24592	36915	594	5347	11467	7756						
											0					
											0					
											0					
											0	250				
												250	250			
												250	250			
												250	250			
												250	250			
											0			0		
											0			0		
											0					
														0		
											0					
	0					0									250	
						0									250	
						0									250	
						0										
						0										
						0										
						0										

0			250
0			
0			
0	5	0	

Bromotriflu	Freon 113	Peracetic A	Cyclohexan	Xylene	Lead Comp	Nickel Com	Selenium	Vanadium	Barium	Manganese	Nitric Acid	Styrene	Butadiene	Ammonium	Vinyl Aceta	Benzene	Trichloroflu	Toluene
				5		0											0	
				5		0											0	
				5														
																		250
																		0
																		750
																		750
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	250	0	250
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0	0
0	0	0	250	5	0	0	0	0	0	0	0	250	250	0	0	0	0	0
120	0	0	0	5	35,280	43,084	0	0	0	0	0	250	250	0	0	0	0	0
0	0	0	5	5	38,414	51,760	960	5,850	22,192	9,137	0	250	250	0	0	0	0	750
0	0	0	5	5	24,592	36,915	594	5,347	11,467	7,756	0	500	250	0	0	0	0	750
17	0	0	37	3	14,041	18,823	222	1,600	4,808	2,413	0	179	143	0	107	36	0	250

				0											
0															
	0	0													
	0	0													
	0	0													
	0	0	0	0											
	0	0	0		0	0									
	0	0	0		0	0	0	0	0	0					
		0	0		0		0	0	0	0					
											0				
												0			
											0				
												5	0		
												9	0		
											0	0	0		
												0	0		
	0										0			40000	
											0			87657	
											0			29930	
											0				
						0									0
						0									0
						0									0
						0									
						0									
						0									
						0									

0 0 0 0

0 0 0

0 0 0

250

0 0

0 0

0 0

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	40,000	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	5	0	87,657	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	9	0	29,930	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

OPERATOR	UNIT_NAME	STATE	YEAR	COAL (THOUSAND SH TONS)	ASH (%)	E X F
SOUTHERN INDIANA GAS ELEC	AB BROWN 1	IN	1993	470.4	7.96	3744.384
SOUTHERN INDIANA GAS ELEC	AB BROWN 2	IN	1993	391.3	8.09	3165.617
AMES MUNI ELEC SYSTEM	AMES TWO 7	IA	1993	40.1	4.47	179.247
AMES MUNI ELEC SYSTEM	AMES TWO 8	IA	1993	154.5	4.45	687.525
NO INDIANA PUBLIC SERVICE	BAILLY 7	IN	1993	492.8	10.15	5001.92
NO INDIANA PUBLIC SERVICE	BAILLY 8	IN	1993	890.3	10.15	9036.545
ILLINOIS POWER CO	BALDWIN 1	IL	1993	1394.4	9.34	13023.7
ILLINOIS POWER CO	BALDWIN 2	IL	1993	1267.5	9.34	11838.45
ILLINOIS POWER CO	BALDWIN 3	IL	1993	1432.6	9.34	13380.48
INDIANA MICHIGAN POWER CO	BREED 1	IN	1993	17.1	11	188.1
IOWA SOUTHERN UTILITIES	BURLINGTON (IA) 1	IA	1993	468.5	7.8	3654.3
PSI ENERGY INC	CAYUGA 1	IN	1993	1170.3	9.51	11129.55
PSI ENERGY INC	CAYUGA 2	IN	1993	1187.9	9.5	11285.05
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 1	IN	1993	666.8	10.69	7128.092
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 2	IN	1993	693.3	10.69	7411.377
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 3	IN	1993	682.5	10.69	7295.925
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 4	IN	1993	648.1	10.69	6928.189
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 5	IN	1993	575.8	10.69	6155.302
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 6	IN	1993	701	10.69	7493.69
CENT ILLINOIS PUBLIC SERV	COFFEEN 1	IL	1993	523.2	9.39	4912.848
CENT ILLINOIS PUBLIC SERV	COFFEEN 2	IL	1993	1152.3	9.44	10877.71
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS 1	IA	1993	205.2	4.64	952.128
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS 2	IA	1993	305	4.65	1418.25
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS 3	IA	1993	1876.8	4.5	8445.6
COMMONWEALTH EDISON CO	CRAWFORD 7	IL	1993	226.7	5.51	1249.117
COMMONWEALTH EDISON CO	CRAWFORD 8	IL	1993	590.5	5.67	3348.135
CRAWFORDSVILLE ELEC LT PR	CRAWFORDSVILLE 5	IN	1993	11.32	8.19	92.7108
SOUTHERN INDIANA GAS ELEC	CULLEY 1	IN	1993	61	8.33	508.13
SOUTHERN INDIANA GAS ELEC	CULLEY 2	IN	1993	264.6	8.22	2175.012
SOUTHERN INDIANA GAS ELEC	CULLEY 3	IN	1993	784	9.76	7651.84
SPRINGFIELD WTR LT & PWR	DALLMAN 1	IL	1993	192.9	10.09	1946.361
SPRINGFIELD WTR LT & PWR	DALLMAN 2	IL	1993	235.5	10.08	2373.84
SPRINGFIELD WTR LT & PWR	DALLMAN 3	IL	1993	528.6	10.08	5328.288

NO INDIANA PUBLIC SERVICE	DH MITCHELL 11	IN	1993	269.1	5.89	1584.999
NO INDIANA PUBLIC SERVICE	DH MITCHELL 4	IN	1993	107.5	5.82	625.65
NO INDIANA PUBLIC SERVICE	DH MITCHELL 5	IN	1993	259.4	6.13	1590.122
NO INDIANA PUBLIC SERVICE	DH MITCHELL 6	IN	1993	392.1	6.04	2368.284
INTERSTATE POWER CO	DUBUQUE 2	IA	1993	0.9	10.91	9.819
INTERSTATE POWER CO	DUBUQUE 3	IA	1993	25.3	10.91	276.023
INTERSTATE POWER CO	DUBUQUE 4	IA	1993	51.5	10.91	561.865
CENTRAL ILLINOIS LIGHT CO	DUCK CREEK 1	IL	1993	1044.8	8.21	8577.808
CORN BELT POWER COOP	EARL F WISDOM 1	IA	1993	19	9.7	184.3
JASPER MUNICIPAL UTIL	EAST FIFTEENTH ST 1	IN	1993	35.2	9.41	331.232
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 1	IL	1993	119.8	5.95	712.81
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 2	IL	1993	462.2	5.96	2754.712
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 3	IL	1993	612.8	6.4	3921.92
INDIANAPOLIS POWER & LT	EW STOUT 5	IN	1993	223.4	8.11	1811.774
INDIANAPOLIS POWER & LT	EW STOUT 6	IN	1993	180.9	8.11	1467.099
INDIANAPOLIS POWER & LT	EW STOUT 7	IN	1993	805.3	8.14	6555.142
CENTRAL IOWA POWER COOP	FE FAIR 1	IA	1993	42.7	9.48	404.796
CENTRAL IOWA POWER COOP	FE FAIR 2	IA	1993	83.7	9.46	791.802
COMMONWEALTH EDISON CO	FISK 19	IL	1993	598.2	5.14	3074.748
PSI ENERGY INC	GALLAGHER 1	IN	1993	301.77	8.66	2613.328
PSI ENERGY INC	GALLAGHER 2	IN	1993	304.82	8.66	2639.741
PSI ENERGY INC	GALLAGHER 3	IN	1993	262.04	8.63	2261.405
PSI ENERGY INC	GALLAGHER 4	IN	1993	244.9	8.78	2150.222
MIDWEST POWER SYSTEMS	GEORGE NEAL 1	IA	1993	443.3	6.29	2788.357
MIDWEST POWER SYSTEMS	GEORGE NEAL 2	IA	1993	832.6	7.84	6527.584
MIDWEST POWER SYSTEMS	GEORGE NEAL 3	IA	1993	1737.7	5.01	8705.877
MIDWEST POWER SYSTEMS	GEORGE NEAL 4	IA	1993	2581.2	5.12	13215.74
PSI ENERGY INC	GIBSON 1	IN	1993	1703.9	10.18	17345.7
PSI ENERGY INC	GIBSON 2	IN	1993	1325.5	10.06	13334.53
PSI ENERGY INC	GIBSON 3	IN	1993	1751.3	10.18	17828.23
PSI ENERGY INC	GIBSON 4	IN	1993	1612.6	10.18	16416.27
PSI ENERGY INC	GIBSON 5	IN	1993	1628.9	8.62	14041.12
CENT ILLINOIS PUBLIC SERV	GRAND TOWER 3	IL	1993	19.3	11.83	228.319
CENT ILLINOIS PUBLIC SERV	GRAND TOWER 4	IL	1993	132.3	11.76	1555.848

ILLINOIS POWER CO	HAVANA 6	IL	1993	569.7	8.75	4984.875
ILLINOIS POWER CO	HENNEPIN 1	IL	1993	81.8	9.94	813.092
ILLINOIS POWER CO	HENNEPIN 2	IL	1993	462.5	9.93	4592.625
INDIANAPOLIS POWER & LT	HT PRITCHARD 3	IN	1993	28.6	7.51	214.786
INDIANAPOLIS POWER & LT	HT PRITCHARD 4	IN	1993	68.4	7.5	513
INDIANAPOLIS POWER & LT	HT PRITCHARD 5	IN	1993	69.7	7.5	522.75
INDIANAPOLIS POWER & LT	HT PRITCHARD 6	IN	1993	210.6	7.5	1579.5
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 3	IL	1993	112.1	9.62	1078.402
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 4	IL	1993	99	9.57	947.43
COMMONWEALTH EDISON CO	JOLIET 6	IL	1993	597.5	4.28	2557.3
COMMONWEALTH EDISON CO	JOLIET 7	IL	1993	1225.3	5.64	6910.692
COMMONWEALTH EDISON CO	JOLIET 8	IL	1993	657.3	5.74	3772.902
ELECTRIC ENERGY INC	JOPPA 1	IL	1993	518.2	7.11	3684.402
ELECTRIC ENERGY INC	JOPPA 2	IL	1993	623.2	7.11	4430.952
ELECTRIC ENERGY INC	JOPPA 3	IL	1993	629.3	7.11	4474.323
ELECTRIC ENERGY INC	JOPPA 4	IL	1993	557.5	7.11	3963.825
ELECTRIC ENERGY INC	JOPPA 5	IL	1993	642	7.11	4564.62
ELECTRIC ENERGY INC	JOPPA 6	IL	1993	672	7.11	4777.92
COMMONWEALTH EDISON CO	KINCAID 1	IL	1993	772.6	9.25	7146.55
COMMONWEALTH EDISON CO	KINCAID 2	IL	1993	1174.3	9.33	10956.22
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 6	IL	1993	38.5	10.17	391.545
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 7	IL	1993	39.9	10.09	402.591
INTERSTATE POWER CO	LANSING 1	IA	1993	3.6	11.52	41.472
INTERSTATE POWER CO	LANSING 2	IA	1993	3.6	11.52	41.472
INTERSTATE POWER CO	LANSING 3	IA	1993	19.3	11.52	222.336
INTERSTATE POWER CO	LANSING 4	IA	1993	529	4.64	2454.56
LOGANSPORT MUNI UTIL	LOGANSPORT 4	IN	1993	33	6.79	224.07
LOGANSPORT MUNI UTIL	LOGANSPORT 5	IN	1993	49	6.79	332.71
IOWA-ILLINOIS GAS & ELEC	LOUISA 1	IA	1993	2157.7	4.99	10766.92
SOUTH ILLINOIS POWER COOP	MARION (IL) 1	IL	1993	21	15.52	325.92
SOUTH ILLINOIS POWER COOP	MARION (IL) 2	IL	1993	12	14.28	171.36
SOUTH ILLINOIS POWER COOP	MARION (IL) 3	IL	1993	13	14.61	189.93
SOUTH ILLINOIS POWER COOP	MARION (IL) 4	IL	1993	476	15.49	7373.24
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 1	IL	1993	10.8	6.62	71.496

CENT ILLINOIS PUBLIC SERV	MEREDOSIA 2	IL	1993	13.8	6.59	90.942
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 3	IL	1993	458.4	6.54	2997.936
HOOSIER ENERGY REC	MEROM 1	IN	1993	1184.8	12.01	14229.45
HOOSIER ENERGY REC	MEROM 2	IN	1993	1393.2	11.98	16690.54
NO INDIANA PUBLIC SERVICE	MICHIGAN CITY 12	IN	1993	1373.1	7.76	10655.26
INTERSTATE POWER CO	ML KAPP 2	IA	1993	510.1	7.59	3871.659
MUSCATINE POWER & WATER	MUSCATINE 7	IA	1993	33.5	9.82	328.97
MUSCATINE POWER & WATER	MUSCATINE 8	IA	1993	80.6	10	806
MUSCATINE POWER & WATER	MUSCATINE 9	IA	1993	537.3	6.65	3573.045
CENT ILLINOIS PUBLIC SERV	NEWTON 1	IL	1993	1195.2	11.01	13159.15
CENT ILLINOIS PUBLIC SERV	NEWTON 2	IL	1993	1360	9.27	12607.2
IOWA SOUTHERN UTILITIES	OTTUMWA 1	IA	1993	2676.1	5.31	14210.09
SOYLAND POWER COOP	PEARL 1	IL	1993	62.8	8.17	513.076
PERU (IN) UTILITIES	PERU (IN) 2	IN	1993	1.18	9.37	11.0566
INDIANAPOLIS POWER & LT	PETERSBURG 1	IN	1993	710.9	8.64	6142.176
INDIANAPOLIS POWER & LT	PETERSBURG 2	IN	1993	1154.4	8.72	10066.37
INDIANAPOLIS POWER & LT	PETERSBURG 3	IN	1993	1456.7	8.64	12585.89
INDIANAPOLIS POWER & LT	PETERSBURG 4	IN	1993	1292.6	8.64	11168.06
COMMONWEALTH EDISON CO	POWERTON 5	IL	1993	1161.9	4.79	5565.501
COMMONWEALTH EDISON CO	POWERTON 6	IL	1993	1733.4	4.88	8458.992
IOWA ELEC LIGHT & POWER	PRAIRIE CREEK 3	IA	1993	112.6	5.7	641.82
IOWA ELEC LIGHT & POWER	PRAIRIE CREEK 4	IA	1993	417.9	5.7	2382.03
HOOSIER ENERGY REC	RATTS 1	IN	1993	266.4	9.42	2509.488
HOOSIER ENERGY REC	RATTS 2	IN	1993	320.4	9.43	3021.372
IOWA-ILLINOIS GAS & ELEC	RIVERSIDE (IA) 5	IA	1993	152.4	9.26	1411.224
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 14	IN	1993	959.3	7.24	6945.332
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 15	IN	1993	938.3	8.25	7740.975
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 17	IN	1993	705.6	10.12	7140.672
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 18	IN	1993	694.9	10.21	7094.929
INDIANA MICHIGAN POWER CO	ROCKPORT 1	IN	1993	4718.8	4.81	22697.43
INDIANA MICHIGAN POWER CO	ROCKPORT 2	IN	1993	4842.8	4.86	23536.01
COMMONWEALTH EDISON (IN)	STATE LINE 3	IN	1993	384.3	3.59	1379.637
COMMONWEALTH EDISON (IN)	STATE LINE 4	IN	1993	406.4	4.4	1788.16
CEDAR FALLS UTILITIES	STREETER 6	IA	1993	1.6	8.4	13.44

CEDAR FALLS UTILITIES	STREETER 7	IA	1993	23.2	8.55	198.36
IOWA ELEC LIGHT & POWER	SUTHERLAND 1	IA	1993	69.9	4.07	284.493
IOWA ELEC LIGHT & POWER	SUTHERLAND 2	IA	1993	73.2	4.07	297.924
IOWA ELEC LIGHT & POWER	SUTHERLAND 3	IA	1993	215.5	4.07	877.085
INDIANA MICHIGAN POWER CO	TANNERS CREEK 1	IN	1993	283.6	10.36	2938.096
INDIANA MICHIGAN POWER CO	TANNERS CREEK 2	IN	1993	92.9	9.98	927.142
INDIANA MICHIGAN POWER CO	TANNERS CREEK 3	IN	1993	164.4	10.48	1722.912
INDIANA MICHIGAN POWER CO	TANNERS CREEK 4	IN	1993	1322.1	9.39	12414.52
ILLINOIS POWER CO	VERMILION 1	IL	1993	111.2	11.8	1312.16
ILLINOIS POWER CO	VERMILION 2	IL	1993	211.6	11.73	2482.068
PSI ENERGY INC	WABASH RIVER 1	IN	1993	147.9	9.07	1341.453
PSI ENERGY INC	WABASH RIVER 2	IN	1993	170.8	9.06	1547.448
PSI ENERGY INC	WABASH RIVER 3	IN	1993	175.38	9.07	1590.697
PSI ENERGY INC	WABASH RIVER 4	IN	1993	143.18	9.07	1298.643
PSI ENERGY INC	WABASH RIVER 5	IN	1993	178.41	9.07	1618.179
PSI ENERGY INC	WABASH RIVER 6	IN	1993	593.35	9.07	5381.685
SOUTHERN INDIANA GAS ELEC	WARRICK 4	IN	1993	993.3	9.76	9694.608
COMMONWEALTH EDISON CO	WAUKEGAN 6	IL	1993	181.4	4.81	872.534
COMMONWEALTH EDISON CO	WAUKEGAN 7	IL	1993	740.7	5.31	3933.117
COMMONWEALTH EDISON CO	WAUKEGAN 8	IL	1993	390.4	5.66	2209.664
RICHMOND POWER & LIGHT	WHITEWATER VALLEY 1	IN	1993	94.2	9.81	924.102
RICHMOND POWER & LIGHT	WHITEWATER VALLEY 2	IN	1993	202	9.81	1981.62
COMMONWEALTH EDISON CO	WILL COUNTY 1	IL	1993	415	4.88	2025.2
COMMONWEALTH EDISON CO	WILL COUNTY 2	IL	1993	458.2	4.57	2093.974
COMMONWEALTH EDISON CO	WILL COUNTY 3	IL	1993	542.5	5.09	2761.325
COMMONWEALTH EDISON CO	WILL COUNTY 4	IL	1993	1069.8	5.15	5509.47
ILLINOIS POWER CO	WOOD RIVER (IL) 4	IL	1993	87.4	8.16	713.184
ILLINOIS POWER CO	WOOD RIVER (IL) 5	IL	1993	683.1	8.22	5615.082
TOTAL				96843.05	1353.45	745361
AVERAGE					8.303374233	
WT. AVERAGE					7.696587462	

OPERATOR	UNIT_NAME	STATE	YEAR	COAL (THOUSAND SH TONS)	SULFUR (%)	E X F
SOUTHERN INDIANA GAS ELEC	AB BROWN 1	IN	1993	470.4	3.67	1726.368
SOUTHERN INDIANA GAS ELEC	AB BROWN 2	IN	1993	391.3	3.69	1443.897
AMES MUNI ELEC SYSTEM	AMES TWO 7	IA	1993	40.1	0.21	8.421
AMES MUNI ELEC SYSTEM	AMES TWO 8	IA	1993	154.5	0.21	32.445
NO INDIANA PUBLIC SERVICE	BAILLY 7	IN	1993	492.8	3	1478.4
NO INDIANA PUBLIC SERVICE	BAILLY 8	IN	1993	890.3	2.97	2644.191
ILLINOIS POWER CO	BALDWIN 1	IL	1993	1394.4	2.58	3597.552
ILLINOIS POWER CO	BALDWIN 2	IL	1993	1267.5	2.58	3270.15
ILLINOIS POWER CO	BALDWIN 3	IL	1993	1432.6	2.58	3696.108
INDIANA MICHIGAN POWER CO	BREED 1	IN	1993	17.1	3.66	62.586
IOWA SOUTHERN UTILITIES	BURLINGTON (IA)	IA	1993	468.5	1.48	693.38
PSI ENERGY INC	CAYUGA 1	IN	1993	1170.3	2.1	2457.63
PSI ENERGY INC	CAYUGA 2	IN	1993	1187.9	2.11	2506.469
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 1	IN	1993	666.8	3.28	2187.104
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 2	IN	1993	693.3	3.28	2274.024
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 3	IN	1993	682.5	3.28	2238.6
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 4	IN	1993	648.1	3.28	2125.768
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 5	IN	1993	575.8	3.28	1888.624
INDIANA KENTUCKY ELEC COR	CLIFTY CREEK 6	IN	1993	701	3.28	2299.28
CENT ILLINOIS PUBLIC SERV	COFFEEN 1	IL	1993	523.2	2.86	1496.352
CENT ILLINOIS PUBLIC SERV	COFFEEN 2	IL	1993	1152.3	2.84	3272.532
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS	IA	1993	205.2	0.31	63.612
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS	IA	1993	305	0.31	94.55
MIDWEST POWER SYSTEMS	COUNCIL BLUFFS	IA	1993	1876.8	0.32	600.576
COMMONWEALTH EDISON CO	CRAWFORD 7	IL	1993	226.7	0.43	97.481
COMMONWEALTH EDISON CO	CRAWFORD 8	IL	1993	590.5	0.42	248.01
CRAWFORDSVILLE ELEC LT P	CRAWFORDSVILL	IN	1993	11.32	1.66	18.7912
SOUTHERN INDIANA GAS ELEC	CULLEY 1	IN	1993	61	1.35	82.35
SOUTHERN INDIANA GAS ELEC	CULLEY 2	IN	1993	264.6	1.35	357.21
SOUTHERN INDIANA GAS ELEC	CULLEY 3	IN	1993	784	2.37	1858.08
SPRINGFIELD WTR LT & PWR	DALLMAN 1	IL	1993	192.9	3.17	611.493
SPRINGFIELD WTR LT & PWR	DALLMAN 2	IL	1993	235.5	3.19	751.245

SPRINGFIELD WTR LT & PWR	DALLMAN 3	IL	1993	528.6	3.19	1686.234
NO INDIANA PUBLIC SERVICE	DH MITCHELL 11	IN	1993	269.1	0.39	104.949
NO INDIANA PUBLIC SERVICE	DH MITCHELL 4	IN	1993	107.5	0.38	40.85
NO INDIANA PUBLIC SERVICE	DH MITCHELL 5	IN	1993	259.4	0.4	103.76
NO INDIANA PUBLIC SERVICE	DH MITCHELL 6	IN	1993	392.1	0.39	152.919
INTERSTATE POWER CO	DUBUQUE 2	IA	1993	0.9	2.8	2.52
INTERSTATE POWER CO	DUBUQUE 3	IA	1993	25.3	2.8	70.84
INTERSTATE POWER CO	DUBUQUE 4	IA	1993	51.5	2.8	144.2
CENTRAL ILLINOIS LIGHT CO	DUCK CREEK 1	IL	1993	1044.8	3.3	3447.84
CORN BELT POWER COOP	EARL F WISDOM 1	IA	1993	19	2.75	52.25
JASPER MUNICIPAL UTIL	EAST FIFTEENTH	IN	1993	35.2	1.39	48.928
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 1	IL	1993	119.8	1.03	123.394
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 2	IL	1993	462.2	1.03	476.066
CENTRAL ILLINOIS LIGHT CO	ED EDWARDS 3	IL	1993	612.8	1.03	631.184
INDIANAPOLIS POWER & LT	EW STOUT 5	IN	1993	223.4	1.77	395.418
INDIANAPOLIS POWER & LT	EW STOUT 6	IN	1993	180.9	1.77	320.193
INDIANAPOLIS POWER & LT	EW STOUT 7	IN	1993	805.3	1.77	1425.381
CENTRAL IOWA POWER COOP	FE FAIR 1	IA	1993	42.7	3.14	134.078
CENTRAL IOWA POWER COOP	FE FAIR 2	IA	1993	83.7	3.16	264.492
COMMONWEALTH EDISON CO	FISK 19	IL	1993	598.2	0.43	257.226
PSI ENERGY INC	GALLAGHER 1	IN	1993	301.77	2.18	657.8586
PSI ENERGY INC	GALLAGHER 2	IN	1993	304.82	2.18	664.5076
PSI ENERGY INC	GALLAGHER 3	IN	1993	262.04	2.18	571.2472
PSI ENERGY INC	GALLAGHER 4	IN	1993	244.9	2.14	524.086
MIDWEST POWER SYSTEMS	GEORGE NEAL 1	IA	1993	443.3	0.43	190.619
MIDWEST POWER SYSTEMS	GEORGE NEAL 2	IA	1993	832.6	0.47	391.322
MIDWEST POWER SYSTEMS	GEORGE NEAL 3	IA	1993	1737.7	0.41	712.457
MIDWEST POWER SYSTEMS	GEORGE NEAL 4	IA	1993	2581.2	0.39	1006.668
PSI ENERGY INC	GIBSON 1	IN	1993	1703.9	1.43	2436.577
PSI ENERGY INC	GIBSON 2	IN	1993	1325.5	1.42	1882.21
PSI ENERGY INC	GIBSON 3	IN	1993	1751.3	1.43	2504.359
PSI ENERGY INC	GIBSON 4	IN	1993	1612.6	1.43	2306.018
PSI ENERGY INC	GIBSON 5	IN	1993	1628.9	2.89	4707.521

CENT ILLINOIS PUBLIC SERV	GRAND TOWER 3	IL	1993	19.3	2.81	54.233
CENT ILLINOIS PUBLIC SERV	GRAND TOWER 4	IL	1993	132.3	2.81	371.763
ILLINOIS POWER CO	HAVANA 6	IL	1993	569.7	0.6	341.82
ILLINOIS POWER CO	HENNEPIN 1	IL	1993	81.8	2.64	215.952
ILLINOIS POWER CO	HENNEPIN 2	IL	1993	462.5	2.64	1221
INDIANAPOLIS POWER & LT	HT PRITCHARD 3	IN	1993	28.6	1.26	36.036
INDIANAPOLIS POWER & LT	HT PRITCHARD 4	IN	1993	68.4	1.26	86.184
INDIANAPOLIS POWER & LT	HT PRITCHARD 5	IN	1993	69.7	1.26	87.822
INDIANAPOLIS POWER & LT	HT PRITCHARD 6	IN	1993	210.6	1.26	265.356
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 3	IL	1993	112.1	2.19	245.499
CENT ILLINOIS PUBLIC SERV	HUTSONVILLE 4	IL	1993	99	2.19	216.81
COMMONWEALTH EDISON CO	JOLIET 6	IL	1993	597.5	0.38	227.05
COMMONWEALTH EDISON CO	JOLIET 7	IL	1993	1225.3	0.47	575.891
COMMONWEALTH EDISON CO	JOLIET 8	IL	1993	657.3	0.4	262.92
ELECTRIC ENERGY INC	JOPPA 1	IL	1993	518.2	1.27	658.114
ELECTRIC ENERGY INC	JOPPA 2	IL	1993	623.2	1.27	791.464
ELECTRIC ENERGY INC	JOPPA 3	IL	1993	629.3	1.27	799.211
ELECTRIC ENERGY INC	JOPPA 4	IL	1993	557.5	1.27	708.025
ELECTRIC ENERGY INC	JOPPA 5	IL	1993	642	1.27	815.34
ELECTRIC ENERGY INC	JOPPA 6	IL	1993	672	1.27	853.44
COMMONWEALTH EDISON CO	KINCAID 1	IL	1993	772.6	3.72	2874.072
COMMONWEALTH EDISON CO	KINCAID 2	IL	1993	1174.3	3.7	4344.91
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 6	IL	1993	38.5	3.22	123.97
SPRINGFIELD WTR LT & PWR	LAKESIDE (IL) 7	IL	1993	39.9	3.21	128.079
INTERSTATE POWER CO	LANSING 1	IA	1993	3.6	2.27	8.172
INTERSTATE POWER CO	LANSING 2	IA	1993	3.6	2.27	8.172
INTERSTATE POWER CO	LANSING 3	IA	1993	19.3	2.27	43.811
INTERSTATE POWER CO	LANSING 4	IA	1993	529	0.34	179.86
LOGANSPORT MUNI UTIL	LOGANSPORT 4	IN	1993	33	0.77	25.41
LOGANSPORT MUNI UTIL	LOGANSPORT 5	IN	1993	49	0.77	37.73
IOWA-ILLINOIS GAS & ELEC	LOUISA 1	IA	1993	2157.7	0.34	733.618
SOUTH ILLINOIS POWER COOP	MARION (IL) 1	IL	1993	21	2.55	53.55
SOUTH ILLINOIS POWER COOP	MARION (IL) 2	IL	1993	12	2.52	30.24

SOUTH ILLINOIS POWER COOP	MARION (IL) 3	IL	1993	13	2.57	33.41
SOUTH ILLINOIS POWER COOP	MARION (IL) 4	IL	1993	476	2.63	1251.88
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 1	IL	1993	10.8	2.97	32.076
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 2	IL	1993	13.8	2.96	40.848
CENT ILLINOIS PUBLIC SERV	MEREDOSIA 3	IL	1993	458.4	2.99	1370.616
HOOSIER ENERGY REC	MEROM 1	IN	1993	1184.8	3.43	4063.864
HOOSIER ENERGY REC	MEROM 2	IN	1993	1393.2	3.45	4806.54
NO INDIANA PUBLIC SERVICE	MICHIGAN CITY 12	IN	1993	1373.1	1.59	2183.229
INTERSTATE POWER CO	ML KAPP 2	IA	1993	510.1	1.97	1004.897
MUSCATINE POWER & WATER	MUSCATINE 7	IA	1993	33.5	2.81	94.135
MUSCATINE POWER & WATER	MUSCATINE 8	IA	1993	80.6	2.78	224.068
MUSCATINE POWER & WATER	MUSCATINE 9	IA	1993	537.3	1.47	789.831
CENT ILLINOIS PUBLIC SERV	NEWTON 1	IL	1993	1195.2	2.64	3155.328
CENT ILLINOIS PUBLIC SERV	NEWTON 2	IL	1993	1360	0.54	734.4
IOWA SOUTHERN UTILITIES	OTTUMWA 1	IA	1993	2676.1	0.35	936.635
SOYLAND POWER COOP	PEARL 1	IL	1993	62.8	3.18	199.704
PERU (IN) UTILITIES	PERU (IN) 2	IN	1993	1.18	2.28	2.6904
INDIANAPOLIS POWER & LT	PETERSBURG 1	IN	1993	710.9	2.5	1777.25
INDIANAPOLIS POWER & LT	PETERSBURG 2	IN	1993	1154.4	2.5	2886
INDIANAPOLIS POWER & LT	PETERSBURG 3	IN	1993	1456.7	2.5	3641.75
INDIANAPOLIS POWER & LT	PETERSBURG 4	IN	1993	1292.6	2.5	3231.5
COMMONWEALTH EDISON CO	POWERTON 5	IL	1993	1161.9	0.32	371.808
COMMONWEALTH EDISON CO	POWERTON 6	IL	1993	1733.4	0.31	537.354
IOWA ELEC LIGHT & POWER	PRAIRIE CREEK 3	IA	1993	112.6	0.72	81.072
IOWA ELEC LIGHT & POWER	PRAIRIE CREEK 4	IA	1993	417.9	0.72	300.888
HOOSIER ENERGY REC	RATTS 1	IN	1993	266.4	3.03	807.192
HOOSIER ENERGY REC	RATTS 2	IN	1993	320.4	2.94	941.976
IOWA-ILLINOIS GAS & ELEC	RIVERSIDE (IA) 5	IA	1993	152.4	2.3	350.52
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 14	IN	1993	959.3	0.51	489.243
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 15	IN	1993	938.3	0.4	375.32
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 17	IN	1993	705.6	2.91	2053.296
NO INDIANA PUBLIC SERVICE	RM SCHAHFER 18	IN	1993	694.9	2.93	2036.057
INDIANA MICHIGAN POWER CO	ROCKPORT 1	IN	1993	4718.8	0.31	1462.828

INDIANA MICHIGAN POWER CO	ROCKPORT 2	IN	1993	4842.8	0.31	1501.268
COMMONWEALTH EDISON (IN	STATE LINE 3	IN	1993	384.3	0.38	146.034
COMMONWEALTH EDISON (IN	STATE LINE 4	IN	1993	406.4	0.4	162.56
CEDAR FALLS UTILITIES	STREETER 6	IA	1993	1.6	2.77	4.432
CEDAR FALLS UTILITIES	STREETER 7	IA	1993	23.2	2.09	48.488
IOWA ELEC LIGHT & POWER	SUTHERLAND 1	IA	1993	69.9	1.01	70.599
IOWA ELEC LIGHT & POWER	SUTHERLAND 2	IA	1993	73.2	1.01	73.932
IOWA ELEC LIGHT & POWER	SUTHERLAND 3	IA	1993	215.5	1.01	217.655
INDIANA MICHIGAN POWER CO	TANNERS CREEK	IN	1993	283.6	0.69	195.684
INDIANA MICHIGAN POWER CO	TANNERS CREEK	IN	1993	92.9	0.7	65.03
INDIANA MICHIGAN POWER CO	TANNERS CREEK	IN	1993	164.4	0.7	115.08
INDIANA MICHIGAN POWER CO	TANNERS CREEK	IN	1993	1322.1	2.38	3146.598
ILLINOIS POWER CO	VERMILION 1	IL	1993	111.2	2.22	246.864
ILLINOIS POWER CO	VERMILION 2	IL	1993	211.6	2.21	467.636
PSI ENERGY INC	WABASH RIVER 1	IN	1993	147.9	2.02	298.758
PSI ENERGY INC	WABASH RIVER 2	IN	1993	170.8	2.03	346.724
PSI ENERGY INC	WABASH RIVER 3	IN	1993	175.38	2.02	354.2676
PSI ENERGY INC	WABASH RIVER 4	IN	1993	143.18	2.02	289.2236
PSI ENERGY INC	WABASH RIVER 5	IN	1993	178.41	2.02	360.3882
PSI ENERGY INC	WABASH RIVER 6	IN	1993	593.35	2.02	1198.567
SOUTHERN INDIANA GAS ELEC	WARRICK 4	IN	1993	993.3	2.58	2562.714
COMMONWEALTH EDISON CO	WAUKEGAN 6	IL	1993	181.4	0.35	63.49
COMMONWEALTH EDISON CO	WAUKEGAN 7	IL	1993	740.7	0.37	274.059
COMMONWEALTH EDISON CO	WAUKEGAN 8	IL	1993	390.4	0.37	144.448
RICHMOND POWER & LIGHT	WHITEWATER VAL	IN	1993	94.2	2.03	191.226
RICHMOND POWER & LIGHT	WHITEWATER VAL	IN	1993	202	2.03	410.06
COMMONWEALTH EDISON CO	WILL COUNTY 1	IL	1993	415	0.31	128.65
COMMONWEALTH EDISON CO	WILL COUNTY 2	IL	1993	458.2	0.31	142.042
COMMONWEALTH EDISON CO	WILL COUNTY 3	IL	1993	542.5	0.33	179.025
COMMONWEALTH EDISON CO	WILL COUNTY 4	IL	1993	1069.8	0.32	342.336
ILLINOIS POWER CO	WOOD RIVER (IL)	IL	1993	87.4	0.68	59.432
ILLINOIS POWER CO	WOOD RIVER (IL)	IL	1993	683.1	0.69	471.339

TOTAL	96843.05	291.93	148593.7904
AVERAGE		1.79	
WT. AVERAGE		1.53	

Sheet Title:	Acetonitrile and acrylonitrile production
Sheet Description:	Emissions are from TRI database. Engineering calculation of the Energy requirements and precursor requirements . This page calculates the vendor emissions from a plant producing PCl3. Not included are raw material production or extraction or water use.
References/Citations:	Faith Keyes and Clarke's Industrial Chemicals By F. A. Lowenheim, M. K. Moran Wiley Interscience, 1975 Perry's Chemical Engineers' Handbook, 6th ed. McGraw Hill, 1984 AP 42 Ed 4 (1985) US EPA SRI Directory of Chemical Producers, US 1993, 1991 editions SRI International, Menlo Park, CA US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993 US International Trade Commission, 11.1994 CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output --

Co-product Allocation Calculations

Source:	US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993 US International Trade Commission, 11.1994

Mwt	Co-product	Quantity	Units	Quantity	Units	1993 Production
53.06	Acetonitrile	1.58E-02	kg	1.00E+00	kg	17,859.00
41.0524	Acrylonitrile	1.00E+00	kg	6.32E+01	kg	1,129,082.00
27.0256	HCN to Acetone cyanoh	2.12E-01	kg	1.34E+01	kg	239,876.00
						1,240,744.98
	Total	1.23	Kg	7.77E+01	Kg	
						As acetone cyanoh

Notes:

LCI components	Unallocated Units	Quantity	Std. Dev.	Allocated Units	Quantity
Air					
Cl2	Kg/kg Acrylonitrile	1.63642E-06		Kg/kg Acetonit	1.3323E-06
Acetonitrile	Kg/kg Acrylonitrile	7.67072E-06		Kg/kg Acetonit	6.24514E-06
Acrolein	Kg/kg Acrylonitrile	1.50005E-07		Kg/kg Acetonit	1.22127E-07
Acrylic acid	Kg/kg Acrylonitrile	5.11381E-09		Kg/kg Acetonit	4.16343E-09
Acrylonitrile	Kg/kg Acrylonitrile	5.52292E-05		Kg/kg Acetonit	4.4965E-05
ammonia	Kg/kg Acrylonitrile	1.44891E-05		Kg/kg Acetonit	1.17964E-05
Hydrogen Cyanide	Kg/kg Acrylonitrile	8.21619E-05		Kg/kg Acetonit	6.68924E-05
Propylene	Kg/kg Acrylonitrile	2.82964E-05		Kg/kg Acetonit	2.30376E-05
acetamide	Kg/kg Acrylonitrile	1.7046E-08		Kg/kg Acetonit	1.38781E-08
acetaldehyde	Kg/kg Acrylonitrile	6.64795E-08		Kg/kg Acetonit	5.41246E-08
Acrylamide	Kg/kg Acrylonitrile	3.80127E-07		Kg/kg Acetonit	3.09481E-07
Pyridine	Kg/kg Acrylonitrile	2.591E-07		Kg/kg Acetonit	2.10947E-07
HC total	Kg/kg Acrylonitrile	0.000188725		Kg/kg Acetonit	0.000153651
Water					
ammonia	Kg/kg Acrylonitrile	4.94335E-07		Kg/kg Acetonit	4.02465E-07
Solid Wastes					
Acetonitrile	Kg/kg Acrylonitrile	5.11381E-09		Kg/kg Acetonit	4.16343E-09
Acrylonitrile	Kg/kg Acrylonitrile	8.52302E-09		Kg/kg Acetonit	6.93905E-09

Shipped out

total	Kg/kg Acrylonitrile	3.74655E-05	Kg/kg Acetonit	3.05027E-05
Acetonitrile	Kg/kg Acrylonitrile	5.79565E-07	Kg/kg Acetonit	4.71855E-07
Acrolein	Kg/kg Acrylonitrile	1.36368E-08	Kg/kg Acetonit	1.11025E-08
Acrylic acid	Kg/kg Acrylonitrile	2.04552E-07	Kg/kg Acetonit	1.66537E-07
Acrylonitrile	Kg/kg Acrylonitrile	6.30703E-08	Kg/kg Acetonit	5.13489E-08
ammonia	Kg/kg Acrylonitrile	3.57967E-05	Kg/kg Acetonit	2.9144E-05
Molybdenum Trioxide	Kg/kg Acrylonitrile	3.23875E-05	Kg/kg Acetonit	2.63684E-05
acetamide	Kg/kg Acrylonitrile	1.67051E-07	Kg/kg Acetonit	1.36005E-07
acetaldehyde	Kg/kg Acrylonitrile	2.55691E-08	Kg/kg Acetonit	2.08171E-08
Acrylamide	Kg/kg Acrylonitrile	5.96611E-07	Kg/kg Acetonit	4.85733E-07
Pyridine	Kg/kg Acrylonitrile	1.87506E-08	Kg/kg Acetonit	1.52659E-08
LCI component	Kg/kg Acrylonitrile	0.006477494	Kg/kg Acetonit	0.005273675
Acetonitrile	Kg/kg Acrylonitrile	7.84118E-08	Kg/kg Acetonit	6.38392E-08
Acrolein	Kg/kg Acrylonitrile	0.000272737	Kg/kg Acetonit	0.000222049
Acrylic acid	Kg/kg Acrylonitrile	0.001056854	Kg/kg Acetonit	0.000860442
Acrylonitrile	Kg/kg Acrylonitrile	0.023864452	Kg/kg Acetonit	0.019429329
Propylene	Kg/kg Acrylonitrile	9.37532E-05	Kg/kg Acetonit	7.63295E-05
Molybdenum Trioxide	Kg/kg Acrylonitrile	0.00015171	Kg/kg Acetonit	0.000123515
acetamide	Kg/kg Acrylonitrile	1.00572E-05	Kg/kg Acetonit	8.18807E-06
acetaldehyde	Kg/kg Acrylonitrile	0.001585281	Kg/kg Acetonit	0.001290663
Acrylamide	Kg/kg Acrylonitrile	0.000136368	Kg/kg Acetonit	0.000111025

Resource Consumption

Heat Energy (fossil fuel)	MJ/kg Acrylonitrile	1.100482758	MJ/kg Acetonit	0.895961957
Electric Power	MJ/kg Acrylonitrile	5.78119E-07	MJ/kg Acetonit	4.70677E-07
ammonia	Kg/kg Acrylonitrile	0.475	Kg/kg Acetonit	0.386722942
propylene	Kg/kg Acrylonitrile	1.175	Kg/kg Acetonit	0.956630435

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the c rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator wa

Conversion Factors

Unit from	Unit to	Multiplier	Reference	
BTU	J	1055.056	CRC, 66th Edition	
Wh	J	3600	CRC, 66th Edition	
bbl CrO	BTU CrO	5800000	Chemical Engineers' Handbook, 6th ed.	
bbl	gal	42	Chemical Engineers' Handbook, 6th ed.	
gal diesel	BTU diesel	118500	Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76	
gal	L	3.785412	CRC, 66th Edition	
kg	lb	2.2046226	CRC, 66th Edition	
yr	day	365		
m^3	bbl (petroleum)	6.289811	CRC, 66th Edition	
gal CrO	lb CrO	7.2		
ton	lb	2000		
gal fuel oil	BTU fuel oil	138000		
cu. ft NG	BTU NG	1032	Chemical Engineers' Handbook, 6th ed.	
lb Coal (dry	BTU Coal	12000	calculation page B	SD=11%
kg NG	MJ NG	46	Calculated page C	SD=13%

Mw Benzen	78.1134
Mw Chlorin	70.9
Mw ClBz	112.56
Mw Cl2Bz	147.01
Mw HCl	36.4609
Mw NaOH	39.9971

molar dry air composition		Mwt	mass composition
N2	0.78084	28.0134	0.75521
O2	0.20946	31.9988	0.231406
CO2	0.00033	44.01	0.000501
Ar	0.00934	39.948	0.012882
total	0.99997	28.96409	1

Ideal gas density at 15 C (60 F) — air (dry)

0.042296	mol/liter	42.29634021	mol/m^3	1.225075005	kg/m^3

Calculations

Acrylonitrile (and acetonitrile) Production 1993

Source:	US Chemical Industry Statistical Handbook 1994			
	Chemical Manufacturers Association, Washington DC			
	m ton	1,129,082.00	Mlb	2489.174177
	MEK production capacity			
Source:	SRI 1991 Directory of Chemical Producers, US			
			Mlb	3055
	Utilization ratio:			0.814786965
	BP Chemicals, Inc. Green Lake @ PMlb			720
	at Port Lavaca TX 77979			
	Calculated production:			586.6466146

Source: Emissions:
TRI database, 1993 data
The Green Lake plant of BP produces acrylonitrile from propylene and some by products including hydrogen cyanide.

The following reported emissions were deemed unrelated to 'nitrile production:	Acetone	diethanolamine
Emissions allocated between the products =	Acetonitrile	Acrolein

Co-Products: Given above.

Resources:	**Energy input** LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
	Fossil fuel (general)	MJ/kg Acrylonitrile	1.100482758			MJ/Kg Acrylonitrile
	Coal	MJ/kg Acrylonitrile	0			Kg/kg Acrylonitrile
	Oil	MJ/kg Acrylonitrile	0	15		Kg/kg Acrylonitrile
	Natural Gas	MJ/kg Acrylonitrile	0			Kg/kg Acrylonitrile
	Hydropower	MJ/kg Acrylonitrile	0			
	Fission	MJ/kg Acrylonitrile	0			
	Electricity (generic)	MJ/kg Acrylonitrile	5.78119E-07			MJ/Kg Acrylonitrile

Energy requirement

					Cal/mol	
Heat	Distillation columns	3 prod is light end	Evaporate acrylonitrile once			7941.4
		1 bottomsproduct	Evaporate acetonitrile twice			16348.4
			10% loss as bottoms			794.14
				cal/gr	MJ/Kg	
			Cooling water	25		0.1027
			Coolers: flow		General flow	
			Kg	Material	Kg/Kg Acrylonitrile	
Electricity	9 minimum pumping stations + 4 coolers	Pump 1 Kg	2.67887721	Acrylonitrile		1.00E+00
				Acetonitrile		1.58E-02
				HCN/Acetonitri		0.456539029

7.8726E-08 MJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

source: Faith Keyes and Clarke's Industrial Chemicals 4th Ed 1975

Material input

LCI component		Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
Oil		Kg/kg Acrylonitrile	0		4	Kg/kg Acrylonitrile
Natural Gas		Kg/kg Acrylonitrile	0		4	Kg/kg Acrylonitrile
Coal		Kg/kg Acrylonitrile	0		4	Kg/kg Acrylonitrile
Naphtha		Kg/kg Acrylonitrile	0		4	Kg/kg Acrylonitrile
ammonia		Kg/kg Acrylonitrile	0.475		4	Kg/kg Acrylonitrile
propylene		Kg/kg Acrylonitrile	1.175		4	Kg/kg Acrylonitrile
Air		Kg/kg Acrylonitrile	0		4	Kg/kg Acrylonitrile
Water	steam	Kg/kg Acrylonitrile	0		4	Kg/kg Acrylonitrile

Air

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
TSP	lb/BP Green Lake	0			Kg/kg Acrylonitrile
SOx	lb/BP Green Lake	0			Kg/kg Acrylonitrile
NOx	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Cl2	lb/BP Green Lake	960			Kg/kg Acrylonitrile
CO2	lb/BP Green Lake	0		3	Kg/kg Acrylonitrile
P4	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Acetonitrile	lb/BP Green Lake	4500			Kg/kg Acrylonitrile
Acrolein	lb/BP Green Lake	88			Kg/kg Acrylonitrile
Acrylic acid	lb/BP Green Lake	3			Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	32400			Kg/kg Acrylonitrile
ammonia	lb/BP Green Lake	8500			Kg/kg Acrylonitrile
Hydrogen Cyanide	lb/BP Green Lake	48200			Kg/kg Acrylonitrile
Propylene	lb/BP Green Lake	16600			Kg/kg Acrylonitrile
Molybdenum Trioxide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
acetamide	lb/BP Green Lake	10			Kg/kg Acrylonitrile
acetaldehyde	lb/BP Green Lake	39			Kg/kg Acrylonitrile
Acrylamide	lb/BP Green Lake	223			Kg/kg Acrylonitrile
Pyridine	lb/BP Green Lake	152			Kg/kg Acrylonitrile
HC total	lb/BP Green Lake	110715			Kg/kg Acrylonitrile
Heavy meta(Cd+Ni+Cr)	lb/BP Green Lake	0			Kg/kg Acrylonitrile

Water

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
COD	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
BOD	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
Acid, H+ (Phosphoric)	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
Metal ions	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
Cl2	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
Acetonitrile	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile

	Acrolein	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
	Acrylic acid	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
	Acrylonitrile	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
	ammonia	lb/BP Green Lake	290		5	Kg/kg Acrylonitrile
	Hydrogen Cyanide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
	Propylene	lb/BP Green Lake	0			Kg/kg Acrylonitrile
	Molybdenum Trioxide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
	acetamide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
	acetaldehyde	lb/BP Green Lake	0			Kg/kg Acrylonitrile
	Acrylamide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
	Pyridine	lb/BP Green Lake	0			Kg/kg Acrylonitrile

Solid waste

	LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
	Production waste (not innert)	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
	Acetonitrile	lb/BP Green Lake	3			Kg/kg Acrylonitrile
	Acrylonitrile	lb/BP Green Lake	5		5	Kg/kg Acrylonitrile
Shipped out	total no catalyst	lb/BP Green Lake	21979		5	Kg/kg Acrylonitrile
	Acetonitrile	lb/BP Green Lake	340		5	Kg/kg Acrylonitrile
	Acrolein	lb/BP Green Lake	8		5	Kg/kg Acrylonitrile
	Acrylic acid	lb/BP Green Lake	120		5	Kg/kg Acrylonitrile
	Acrylonitrile	lb/BP Green Lake	37		5	Kg/kg Acrylonitrile
	ammonia	lb/BP Green Lake	21000		5	Kg/kg Acrylonitrile
	Hydrogen Cyanide	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
	Propylene	lb/BP Green Lake	0		5	Kg/kg Acrylonitrile
To recycle	Molybdenum Trioxide	lb/BP Green Lake	*19000*		5	Kg/kg Acrylonitrile
	acetamide	lb/BP Green Lake	98			Kg/kg Acrylonitrile
	acetaldehyde	lb/BP Green Lake	15			Kg/kg Acrylonitrile
	Acrylamide	lb/BP Green Lake	350			Kg/kg Acrylonitrile
	Pyridine	lb/BP Green Lake	11			Kg/kg Acrylonitrile

Heavy metals (Cadmium, Nickel, CHb/BP Green Lake		0		5	Kg/kg Acrylonitrile

Deep well injection

LCI component	Raw/ Input Units	Raw/ Input Quan.	Raw/ Input Std. Dev.	DQI	Transformed Units
Acetonitrile	lb/BP Green Lake	3,800,000.00			Kg/kg Acrylonitrile
Acrolein	lb/BP Green Lake	46			Kg/kg Acrylonitrile
Acrylic acid	lb/BP Green Lake	160000			Kg/kg Acrylonitrile
Acrylonitrile	lb/BP Green Lake	620000			Kg/kg Acrylonitrile
ammonia	lb/BP Green Lake	14000000			Kg/kg Acrylonitrile
Hydrogen Cyanide	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Propylene	lb/BP Green Lake	0			Kg/kg Acrylonitrile
Molybdenum Trioxide	lb/BP Green Lake	55000			Kg/kg Acrylonitrile
acetamide	lb/BP Green Lake	89000			Kg/kg Acrylonitrile
acetaldehyde	lb/BP Green Lake	5900			Kg/kg Acrylonitrile
Acrylamide	lb/BP Green Lake	930000			Kg/kg Acrylonitrile
Pyridine	lb/BP Green Lake	80000			Kg/kg Acrylonitrile

Sheet End ======== ================= =============== ============ ========== ========== =============

		336.5812288		17859	0.014394
	720	27503.43463		1129082	0.910003
	60	3470.930401	69.11	93803.98	0.075603
hydrin		60			
	Std. Dev.	DQI			
		3			
		3			
		3			
		3			

taken and the proper
o-product allocation

as reported.

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and sulfur = 0.5%

kg air per kg
component
1.324134
4.321406
1994.319
77.62792

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Cyanide compour	Hydroquinone	Formaldehyde	methanol	Chlorine	Benzene	
Acrylic acid	Acrylonitrile	ammonia	Hydrogen Cyanide		Propylene	Molybdenum

Transformed Quan.	Transformed Std. Dev.
1.100482758	
0	
0	
0	
0	
0	
5.78119E-07	

MJ/kg Acrylonitrile	
0.794673909	
0.288925823	
0.016883025	
1.100482758	
10.71550884	Kg water

Sp Gr	Sp visc	numper of pumping stages			Electric Demand	
0.806	0.7	Absorber, Separator, Colu		5	**2.22E-07**	
0.7857	0.7	condenser and storage		2	**1.37E-09**	
1	2	Absorber, Separator		2	**1.44E-07**	
	These are guesses		Coolers		**2.11E-07**	
			Total		5.78E-07	MJ/Kg Acrylonitrile

Transformed Quan.	Transformed Std. Dev.	
0		
0		
0		
0		
0.475		(all out into water emission)
1.175		
0		
0		

Transformed Quan.	Transformed Std. Dev.
0	
0	
0	
1.63642E-06	
0	
0	
7.67072E-06	
1.50005E-07	
5.11381E-09	
5.52292E-05	
1.44891E-05	
8.21619E-05	
2.82964E-05	
0	
1.7046E-08	
6.64795E-08	
3.80127E-07	
2.591E-07	
0.000188725	
0	

Transformed Quan.	Transformed Std. Dev.
0	
0	
0	
0	
0	
0	

0
0
0
4.94335E-07
0
0
0
0
0
0
0

Transformed Quan.	Transformed Std. Dev.
0	
5.11381E-09	
8.52302E-09	
3.74655E-05	
5.79565E-07	
1.36368E-08	
2.04552E-07	
6.30703E-08	
3.57967E-05	
0	
0	
3.23875E-05	
1.67051E-07	
2.55691E-08	
5.96611E-07	
1.87506E-08	

0

Transformed Quan.	Transformed Std. Dev.
0.006477494	
7.84118E-08	
0.000272737	
0.001056854	
0.023864452	
0	
0	
9.37532E-05	
0.00015171	
1.00572E-05	
0.001585281	
0.000136368	

TABLE 1. INVENTORY FOR BASELINE PBXN-109 DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

			HE Washout			Process
	1	2	3	4	5	Total
PBXN-109	(525.00)	0.00	509.25	0.00	15.75	0
TNAZ/Al	0.00	0.00	0.00	0.00	0.00	0
Asphalt	(18.50)	0.00	0.00	0.00	18.50	0
Bomb Case	(1,390.00)	0.00	0.00	0.00	1,390.00	0
Potting	(3.00)	0.00	0.00	0.00	3.00	0
Felt Pad	?	0.00	0.00	0.00	0.00	0
Thermal Insulation	(25.00)	0.00	0.00	0.00	25.00	0
TCA (solvent)	0.00	0.00	0.00	0.00	0.00	0
Water	0.00	(63,050.40)	0.00	63,050.40	0.00	0
Steam	0.00	0.00	0.00	0.00	0.00	0
Fuel	0.00	0.00	0.00	0.00	0.00	0
Air	0.00	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0.00	(1,738.00)	0.00	0.00	0.00	-1738
Activated Carbon	0.00	0.00	0.00	0.00	0.00	0
CO	0.00	0.00	0.00	0.00	0.00	0
N2	0.00	0.00	0.00	0.00	0.00	0
H2O	0.00	0.00	0.00	0.00	0.00	0
H2	0.00	0.00	0.00	0.00	0.00	0
CO2	0.00	0.00	0.00	0.00	0.00	0
H	0.00	0.00	0.00	0.00	0.00	0
HO	0.00	0.00	0.00	0.00	0.00	0
NO	0.00	0.00	0.00	0.00	0.00	0
Al	0.00	0.00	0.00	0.00	0.00	0
O	0.00	0.00	0.00	0.00	0.00	0
CH4	0.00	0.00	0.00	0.00	0.00	0
NH3	0.00	0.00	0.00	0.00	0.00	0
C2H4	0.00	0.00	0.00	0.00	0.00	0
C3H6	0.00	0.00	0.00	0.00	0.00	0
C2H6	0.00	0.00	0.00	0.00	0.00	0

C2H2	0.00	0.00	0.00	0.00	0.00	0
C3H8	0.00	0.00	0.00	0.00	0.00	0
CHN	0.00	0.00	0.00	0.00	0.00	0
C	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0
Ash	0.00	0.00	0.00	0.00	0.00	0

			Burning Ground			Process
	3	6	7	8	9	Total
PBXN-109	(0.00)	0.00	0.00	0.00	0.00	0
TNAZ/Al	0.00	0.00	0.00	0.00	0.00	0
Asphalt	0.00	0.00	0.00	0.00	0.00	0
Bomb Case	0.00	0.00	0.00	0.00	0.00	0
Potting	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0.00	0.00	0.00	0.00	0.00	0
Water	0.00	0.00	0.00	0.00	0.00	0
Steam	0.00	0.00	0.00	0.00	0.00	0
Fuel	0.00 ?		0.00	0.00	0.00	0
Air	0.00	0.00 ?		0.00	0.00	0
Electricity, kwh/bomb	0.00	0.00	0.00	0.00	0.00	0
Activated Carbon	0.00	0.00	0.00	0.00	0.00	0
CO	0.00	0.00	0.00 ?		0.00	0
N2	0.00	0.00	0.00 ?		0.00	0
H2O	0.00	0.00	0.00 ?		0.00	0
H2	0.00	0.00	0.00 ?		0.00	0
CO2	0.00	0.00	0.00 ?		0.00	0
H	0.00	0.00	0.00 ?		0.00	0
HO	0.00	0.00	0.00 ?		0.00	0
NO	0.00	0.00	0.00 ?		0.00	0
Al	0.00	0.00	0.00 ?		0.00	0

O	0.00	0.00	0.00 ?		0.00	0
CH4	0.00	0.00	0.00	0.00	0.00	0
NH3	0.00	0.00	0.00	0.00	0.00	0
C2H4	0.00	0.00	0.00	0.00	0.00	0
C3H6	0.00	0.00	0.00	0.00	0.00	0
C2H6	0.00	0.00	0.00	0.00	0.00	0
C2H2	0.00	0.00	0.00	0.00	0.00	0
C3H8	0.00	0.00	0.00	0.00	0.00	0
CHN	0.00	0.00	0.00	0.00	0.00	0
C	0.00	0.00	0.00	0.00	52.38	52.38
Flue Gas	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0.00	0.00	0.00	0.00	192.06	192.06
Ash	0.00	0.00	0.00	0.00	244.44	244.44

			Wastewater Treatment		Process	Solid	Wastewater
	4	10	11	12	Total	Wastes	Emissions
PBXN-109	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	0.00	0.00	0.00	0.00	0	0	0
Asphalt	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	0.00	0.00	0.00	0.00	0	0	0
Potting	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0.00	0.00	0.00	0.00	0	0	0
Water	0.00	0.00	0.75	63,049.65	63050.4	0.752164	63049.648
Steam	0.00	0.00	0.00	0.00	0	0	0
Fuel	0.00	0.00	0.00	0.00	0	0	0
Air	0.00	0.00	0.00	0.00	0	0	0
Electricity, kwh/bomb	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0.00	(14.29)	14.29	0.00	0	14.291115	0
CO	0.00	0.00	0.00	0.00	0	0	0
N2	0.00	0.00	0.00	0.00	0	0	0
H2O	0.00	0.00	0.00	0.00	0	0	0

H2	0.00	0.00	0.00	0.00	0	0	0
CO2	0.00	0.00	0.00	0.00	0	0	0
H	0.00	0.00	0.00	0.00	0	0	0
HO	0.00	0.00	0.00	0.00	0	0	0
NO	0.00	0.00	0.00	0.00	0	0	0
Al	0.00	0.00	0.00	0.00	0	0	0
O	0.00	0.00	0.00	0.00	0	0	0
CH4	0.00	0.00	0.00	0.00	0	0	0
NH3	0.00	0.00	0.00	0.00	0	0	0
C2H4	0.00	0.00	0.00	0.00	0	0	0
C3H6	0.00	0.00	0.00	0.00	0	0	0
C2H6	0.00	0.00	0.00	0.00	0	0	0
C2H2	0.00	0.00	0.00	0.00	0	0	0
C3H8	0.00	0.00	0.00	0.00	0	0	0
CHN	0.00	0.00	0.00	0.00	0	0	0
C	0.00	0.00	0.00	0.00	0	0	0
Flue Gas	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0	0	0
Al2O3	0.00	0.00	0.00	0.00	0	0	0
Ash	0.00	0.00	0.00	0.00	0	0	0

	Solvent Soak				Process
	5	13	14	15	Total
PBXN-109	(15.75)	0.00	15.75	0.00	0
TNAZ/Al	0.00	0.00	0.00	0.00	0
Asphalt	(18.50)	0.00	18.50	0.00	0
Bomb Case	(1,390.00)	0.00	0.00	1,390.00	0
Potting	(3.00)	0.00	0.00	3.00	0
Felt Pad	0.00	0.00	0.00	0.00	0
Thermal Insulation	(25.00)	0.00	0.00	25.00	0
TCA (solvent)	0.00	(212.50)	212.50	0.00	0
Water	0.00	0.00	0.00	0.00	0
Steam	0.00	0.00	0.00	0.00	0
Fuel	0.00	0.00	0.00	0.00	0

Air	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0.00	0.00	0.00	0.00	0
Activated Carbon	0.00	0.00	0.00	0.00	0
CO	0.00	0.00	0.00	0.00	0
N2	0.00	0.00	0.00	0.00	0
H2O	0.00	0.00	0.00	0.00	0
H2	0.00	0.00	0.00	0.00	0
CO2	0.00	0.00	0.00	0.00	0
H	0.00	0.00	0.00	0.00	0
HO	0.00	0.00	0.00	0.00	0
NO	0.00	0.00	0.00	0.00	0
Al	0.00	0.00	0.00	0.00	0
O	0.00	0.00	0.00	0.00	0
CH4	0.00	0.00	0.00	0.00	0
NH3	0.00	0.00	0.00	0.00	0
C2H4	0.00	0.00	0.00	0.00	0
C3H6	0.00	0.00	0.00	0.00	0
C2H6	0.00	0.00	0.00	0.00	0
C2H2	0.00	0.00	0.00	0.00	0
C3H8	0.00	0.00	0.00	0.00	0
CHN	0.00	0.00	0.00	0.00	0
C	0.00	0.00	0.00	0.00	0
Flue Gas	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0
Al2O3	0.00	0.00	0.00	0.00	0
Ash	0.00	0.00	0.00	0.00	0

	Incinerator					Process	Air	Solid
	14	16	17	18	19	Total	Emissions	Wastes
PBXN-109	-15.75	0.00	0.00	0.00	0.00	-15.75	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0	0	0
Asphalt	-18.5	0.00	0.00	0.00	0.00	-18.5	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0	0

Felt Pad	0	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	-212.5	0.00	0.00	0.00	0.00	-212.5	0	0
Water	0	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0	0
Fuel	0 ?		0.00	0.00	0.00	0	0	0
Air	0	0.00 ?		0.00	0.00	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00 ?		0.00	0 ?		0
N2	0	0.00	0.00 ?		0.00	0 ?		0
H2O	0	0.00	0.00 ?		0.00	0 ?		0
H2	0	0.00	0.00	0.00	0.00	0	0	0
CO2	0	0.00	0.00 ?		0.00	0 ?		0
H	0	0.00	0.00	0.00	0.00	0	0	0
HO	0	0.00	0.00	0.00	0.00	0	0	0
NO	0	0.00	0.00	0.00	0.00	0	0	0
Al	0	0.00	0.00	0.00	0.00	0	0	0
O	0	0.00	0.00	0.00	0.00	0	0	0
CH4	0	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0	0
C	0	0.00	0.00	0.00	0.00	0	0	0
Flue Gas	0	0.00	0.00 ?		0.00	0 ?		0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0	0	0
Ash	0	0.00	0.00	0.00 ?		0	0 ?	
						Process	Solid	Recycle

	15	20	21	22	23	24	Total	Waste	Scrap
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Asphalt	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	1,390.00	0	0	1390
Potting	-3	0.00	0.00	0.00	0.00	0.00	-3	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	-25	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Fuel	0 ?		0.00	0.00	0.00	0.00	0	0	0
Air	0	0.00 ?		0.00	0.00	0.00	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00 ?		0.00	0.00	0	0	0
N2	0	0.00	0.00 ?		0.00	0.00	0	0	0
H2O	0	0.00	0.00 ?		0.00	0.00	0	0	0
H2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CO2	0	0.00	0.00 ?		0.00	0.00	0	0	0
H	0	0.00	0.00	0.00	0.00	0.00	0	0	0
HO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
NO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Al	0	0.00	0.00	0.00	0.00	0.00	0	0	0
O	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C	0	0.00	0.00	0.00	0.00	0.00	0	0	0

Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0.00	0.00 ?		0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Ash	0	0.00	0.00	0.00 ?		0.00	0 ?		0

TABLE 2. INVENTORY FOR OPTION 1 PBXN-109 DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

			HE Removal		
	1	2	3	4	5
PBXN-109	(525.00)	0.00	509.25	0.00	15.75
TNAZ/Al	0.00	0.00	0.00	0.00	0.00
Asphalt	(18.50)	0.00	0.00	0.00	18.50
Bomb Case	(1,390.00)	0.00	0.00	0.00	1,390.00
Potting	(3.00)	0.00	0.00	0.00	3.00
Felt Pad	?	0.00	0.00	0.00	0.00
Thermal Insulation	(25.00)	0.00	0.00	0.00	25.00
TCA (solvent)	0.00	0.00	0.00	0.00	0.00
Water	0.00	(63,050.40)	0.00	63,050.40	0.00
Steam	0.00	0.00	0.00	0.00	0.00
Fuel	0.00	0.00	0.00	0.00	0.00
Air	0.00	0.00	0.00	0.00	0.00
Electricity, kwh/bomb	0.00	(1,738.00)	0.00	0.00	0.00
Activated Carbon	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	0.00
N2	0.00	0.00	0.00	0.00	0.00
H2O, vapor	0.00	0.00	0.00	0.00	0.00
H2	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00
HO	0.00	0.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	0.00
Al	0.00	0.00	0.00	0.00	0.00
O	0.00	0.00	0.00	0.00	0.00
CH4	0.00	0.00	0.00	0.00	0.00
NH3	0.00	0.00	0.00	0.00	0.00
C2H4	0.00	0.00	0.00	0.00	0.00
C3H6	0.00	0.00	0.00	0.00	0.00
C2H6	0.00	0.00	0.00	0.00	0.00
C2H2	0.00	0.00	0.00	0.00	0.00
C3H8	0.00	0.00	0.00	0.00	0.00
CHN	0.00	0.00	0.00	0.00	0.00
C	0.00	0.00	0.00	0.00	0.00

	3	6	Burning Ground 7	8	9	Solid Waste	Air Emissions	Resource Consumption
Flue Gas	0.00	0.00	0.00	0.00	0.00			
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00			
Al2O3	0.00	0.00	0.00	0.00	0.00			
Ash	0.00	0.00	0.00	0.00	0.00			
PBXN-109	-509.25	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0	0	0
Asphalt	0	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0	0
Water	0	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0	0
Fuel	0 ?		0.00	0.00	0.00	0	0	0
Air	0	0.00 ?		0.00	0.00	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00 ?		0.00	0 ?		0
N2	0	0.00	0.00 ?		0.00	0 ?		0
H2O, vapor	0	0.00	0.00 ?		0.00	0 ?		0
H2	0	0.00	0.00 ?		0.00	0 ?		0
CO2	0	0.00	0.00 ?		0.00	0 ?		0
H	0	0.00	0.00 ?		0.00	0 ?		0
HO	0	0.00	0.00 ?		0.00	0 ?		0
NO	0	0.00	0.00 ?		0.00	0 ?		0
Al	0	0.00	0.00 ?		0.00	0 ?		0
O	0	0.00	0.00 ?		0.00	0 ?		0
CH4	0	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0	0

C3H8	0	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0	0
C	0	0.00	0.00	0.00	52.38	52.38	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	192.06	192.06	0	0
Ash	0	0.00	0.00	0.00	244.44	244.44	0	0

		Wastewater Treatment					Solid	Wastewater
	4	10	11	12	16	22	Waste	Emissions
PBXN-109	0	0.00	0.00	0.00	0	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0	0	0
Asphalt	0	0.00	0.00	0.00	0	0	0	0
Bomb Case	0	0.00	0.00	0.00	0	0	0	0
Potting	0	0.00	0.00	0.00	0	0	0	0
Felt Pad	0	0.00	0.00	0.00	0	0	0	0
Thermal Insulation	0	0.00	0.00	0.00	0	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0	0	0	0
Water	-63050.4	0.00	0.77	64,390.94	-1296	-45.3048	0.7681651	64390.937
Steam	0	0.00	0.00	0.00	0	0	0	0
Fuel	0	0.00	0.00	0.00	0	0	0	0
Air	0	0.00	0.00	0.00	0	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0	0	0
Activated Carbon	0	(14.60)	14.60	0.00	0	0	14.595138	0
CO	0	0.00	0.00	0.00	0	0	0	0
N2	0	0.00	0.00	0.00	0	0	0	0
H2O, vapor	0	0.00	0.00	0.00	0	0	0	0
H2	0	0.00	0.00	0.00	0	0	0	0
CO2	0	0.00	0.00	0.00	0	0	0	0
H	0	0.00	0.00	0.00	0	0	0	0
HO	0	0.00	0.00	0.00	0	0	0	0
NO	0	0.00	0.00	0.00	0	0	0	0
Al	0		0.00	0.00	0	0	0	0
O	0	0.00	0.00	0.00	0	0	0	0
CH4	0	0.00	0.00	0.00	0	0	0	0
NH3	0	0.00	0.00	0.00	0	0	0	0
C2H4	0	0.00	0.00	0.00	0	0	0	0

C3H6	0	0.00	0.00	0.00	0	0	0	0
C2H6	0	0.00	0.00	0.00	0	0	0	0
C2H2	0	0.00	0.00	0.00	0	0	0	0
C3H8	0	0.00	0.00	0.00	0	0	0	0
CHN	0	0.00	0.00	0.00	0	0	0	0
C	0	0.00	0.00	0.00	0	0	0	0
Flue Gas	0	0.00	0.00	0.00	0	0	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0	0	0
Al2O3	0	0.00	0.00	0.00	0	0	0	0
Ash	0	0.00	0.00	0.00	0	0	0	0

				Asphalt Liner Meltout					Wastewater
	5	13	14	15	16	17	18	19	Emissions
PBXN-109	-15.75	0.00	0.00	0.00	0.00	0.00	15.75	0.00	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Asphalt	-18.5	0.00	0.00	0.00	0.00	0.00	18.32	0.18	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	0.00	0.00	1,390.00	0
Potting	-3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Water	0	0.00	(1,296.00)	0.00	1,296.00	714.00	0.00	0.00	714
Steam	0	(714.00)	0.00	0.00	0.00	0.00	0.00	0.00	0
Fuel	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Air	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
N2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
H2O, vapor	0	0.00	0.00	238.00	0.00	0.00	0.00	0.00	0
H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CO2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
H	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

CH4	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

	Solidification			
	18	20	21	22
PBXN-109	-15.75	0.00	15.75	0.00
TNAZ/Al	0	0.00	0.00	0.00
Asphalt	-18.315	0.00	18.32	0.00
Bomb Case	0	0.00	0.00	0.00
Potting	0	0.00	0.00	0.00
Felt Pad	0	0.00	0.00	0.00
Thermal Insulation	0	0.00	0.00	0.00
TCA (solvent)	0	0.00	0.00	0.00
Water	0	(46.00)	0.70	45.30
Steam	0	0.00	0.00	0.00
Fuel	0	0.00	0.00	0.00
Air	0	0.00	0.00	0.00
Electricity, kwh/bomb	0	0.00	0.00	0.00
Activated Carbon	0	0.00	0.00	0.00
CO	0	0.00	0.00	0.00
N2	0	0.00	0.00	0.00
H2O, vapor	0	0.00	0.00	0.00
H2	0	0.00	0.00	0.00
CO2	0	0.00	0.00	0.00
H	0	0.00	0.00	0.00
HO	0	0.00	0.00	0.00

NO	0	0.00	0.00	0.00
Al	0	0.00	0.00	0.00
O	0	0.00	0.00	0.00
CH4	0	0.00	0.00	0.00
NH3	0	0.00	0.00	0.00
C2H4	0	0.00	0.00	0.00
C3H6	0	0.00	0.00	0.00
C2H6	0	0.00	0.00	0.00
C2H2	0	0.00	0.00	0.00
C3H8	0	0.00	0.00	0.00
CHN	0	0.00	0.00	0.00
C	0	0.00	0.00	0.00
Flue Gas	0	0.00	0.00	0.00
Total gaseous pollutant	0	0.00	0.00	0.00
Al2O3	0	0.00	0.00	0.00
Ash	0	0.00	0.00	0.00

			Burning Grounds			Air	Solid
	21	23	24	25	26	Emissions	Waste
PBXN-109	-15.75	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0
Water	-0.695204082	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?		0.00	0.00	0.00	0	0
Air	0	0.00 ?		0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00 ?		0.00 ?		0
N2	0	0.00	0.00 ?		0.00 ?		0
H2O, vapor	0	0.00	0.00 ?		0.00 ?		0
H2	0	0.00	0.00	0.00	0.00	0	0

CO2	0	0.00	0.00 ?		0.00 ?		0
H	0	0.00	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00 ?		0.00 ?		0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0	0
Ash	0 ?		0.00	0.00	0.00	0	0

	19	27	Flashing 28	29	30	31	Solid Waste	Recycle
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0	0
Asphalt	-0.185	0.00	0.00	0.00	0.00	0.00	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	1,390.00	0	1390
Potting	0	0.00	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?		0.00	0.00	0.00	0.00	0	0
Air	0	0.00 ?		0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00 ?		0.00	0.00	0	0

N2	0	0.00	0.00	0.00	0.00	0.00	0	0
H2O, vapor	0	0.00	0.00 ?		0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00 ?		0.00	0.00	0	0
H	0	0.00	0.00	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00 ?		0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00 ?		0.00 ?		0

TABLE 3. INVENTORY FOR OPTION 2 TNAZ DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

			HE Removal		
	1	2	3	4	5
PBXN-109	0.00	0.00	0.00	0.00	0.00
TNAZ/Al	(525.00)	0.00	509.25	0.00	15.75
Asphalt	(18.50)	0.00	0.00	0.00	18.50
Bomb Case	(1,390.00)	0.00	0.00	0.00	1,390.00
Potting	(3.00)	0.00	0.00	0.00	3.00
Felt Pad	?	0.00	0.00	0.00	?
Thermal Insulation	(25.00)	0.00	0.00	0.00	25.00
TCA (solvent)	0.00	0.00	0.00	0.00	0.00
Water	0.00	(63,050.40)	0.00	63,050.40	0.00
Steam	0.00	0.00	0.00	0.00	0.00
Fuel	0.00	0.00	0.00	0.00	0.00
Air	0.00	0.00	0.00	0.00	0.00
Electricity, kwh/bomb	0.00	(1,738.00)	0.00	0.00	0.00
Activated Carbon	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	0.00	0.00
N2	0.00	0.00	0.00	0.00	0.00
H2O	0.00	0.00	0.00	0.00	0.00
H2	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00
H	0.00	0.00	0.00	0.00	0.00
HO	0.00	0.00	0.00	0.00	0.00
NO	0.00	0.00	0.00	0.00	0.00
Al	0.00	0.00	0.00	0.00	0.00
O	0.00	0.00	0.00	0.00	0.00
CH4	0.00	0.00	0.00	0.00	0.00
NH3	0.00	0.00	0.00	0.00	0.00
C2H4	0.00	0.00	0.00	0.00	0.00
C3H6	0.00	0.00	0.00	0.00	0.00
C2H6	0.00	0.00	0.00	0.00	0.00
C2H2	0.00	0.00	0.00	0.00	0.00
C3H8	0.00	0.00	0.00	0.00	0.00
CHN	0.00	0.00	0.00	0.00	0.00
C	0.00	0.00	0.00	0.00	0.00

Flue Gas	0.00	0.00	0.00	0.00	0.00
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00
Al2O3	0.00	0.00	0.00	0.00	0.00
Ash	0.00	0.00	0.00	0.00	0.00

			Burning Ground			Air	Solid
	3	6	7	8	9	Emissions	Waste
PBXN-109	0	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	-509.25	0.00	0.00	0.00	0.00	0	0
Asphalt	0	0.00	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0
Water	0	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?		0.00	0.00	0.00	0	0
Air	0	0.00 ?		0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00	(174.16)	0.00	-174.1635	0
N2	0	0.00	0.00	(118.81)	0.00	-118.8056	0
H2O	0	0.00	0.00	(9.62)	0.00	-9.6224	0
H2	0	0.00	0.00	(6.93)	0.00	-6.9258	0
CO2	0	0.00	0.00	(6.31)	0.00	-6.3147	0
H	0	0.00	0.00	(0.50)	0.00	-0.5044	0
HO	0	0.00	0.00	(0.35)	0.00	-0.3492	0
NO	0	0.00	0.00	(0.05)	0.00	-0.0485	0
Al	0	0.00	0.00	(0.05)	0.00	-0.0485	0
O	0	0.00	0.00	(0.05)	0.00	-0.0485	0
CH4	0	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0

CHN	0	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	52.38	0	52.38
Flue Gas	0	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	(175.11)	0.00	-175.1141	0
Al2O3	0	0.00	0.00	0.00	(192.29)	0	-192.2928
Ash	0	0.00	0.00	0.00	(139.91)	0	-139.9128

			Wastewater Treament				Solid	Wastewater
	4	10	11	12	16	21	Waste	Emissions
PBXN-109	0	0.00	0.00	0.00	0		0	0
TNAZ/Al	0	0.00	0.00	0.00	0		0	0
Asphalt	0	0.00	0.00	0.00	0		0	0
Bomb Case	0	0.00	0.00	0.00	0		0	0
Potting	0	0.00	0.00	0.00	0		0	0
Felt Pad	0	0.00	0.00	0.00	0		0	0
Thermal Insulation	0	0.00	0.00	0.00	0		0	0
TCA (solvent)	0	0.00	0.00	0.00	0		0	0
Water	-63050.4	0.00	0.74	61,706.97	1296		0.7361462	61706.969
Steam	0	0.00	0.00	0.00	0		0	0
Fuel	0	0.00	0.00	0.00	0		0	0
Air	0	0.00	0.00	0.00	0		0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0		0	0
Activated Carbon	0	13.99	13.99	0.00	0		13.986778	0
CO	0	0.00	0.00	0.00	0		0	0
N2	0	0.00	0.00	0.00	0		0	0
H2O	0	0.00	0.00	0.00	0		0	0
H2	0	0.00	0.00	0.00	0		0	0
CO2	0	0.00	0.00	0.00	0		0	0
H	0	0.00	0.00	0.00	0		0	0
HO	0	0.00	0.00	0.00	0		0	0
NO	0	0.00	0.00	0.00	0		0	0
Al	0	0.00	0.00	0.00	0		0	0
O	0	0.00	0.00	0.00	0		0	0
CH4	0	0.00	0.00	0.00	0		0	0
NH3	0	0.00	0.00	0.00	0		0	0
C2H4	0	0.00	0.00	0.00	0		0	0
C3H6	0	0.00	0.00	0.00	0		0	0

C2H6	0	0.00	0.00	0.00	0		0	0		
C2H2	0	0.00	0.00	0.00	0		0	0		
C3H8	0	0.00	0.00	0.00	0		0	0		
CHN	0	0.00	0.00	0.00	0		0	0		
C	0	0.00	0.00	0.00	0		0	0		
Flue Gas	0	0.00	0.00	0.00	0		0	0		
Total gaseous pollutant	0	0.00	0.00	0.00	0		0	0		
Al2O3	0	0.00	0.00	0.00	0		0	0		
Ash	0	0.00	0.00	0.00	0		0	0		
			Asphalt Liner Meltout						Air	Wastewater
	5	13	14	15	16	17	18	19	Emissions	Emissions
PBXN-109	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
TNAZ/Al	-15.75	0.00	0.00	0.00	0.00	0	15.75	0.00	0	0
Asphalt	-18.5	0.00	0.00	0.00	0.00	0	18.32	0.18	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	0	0.00	1,390.00	0	0
Potting	-3	0.00	0.00	0.00	0.00	0	0.00	3.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0.00 ?		0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0	0.00	25.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Water	0	0.00	(1,296.00)	0.00	(1,296.00)	-714	0.00	0.00	0	-714
Steam	0	(714.00)	0.00	0.00	0.00	0	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
CO	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
H2O	0	0.00	0.00	238.00	0.00	0	0.00	0.00	238	0
H2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0

CH4	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0.00	0	0.00	0.00	0	0

		Solidification		
	18	20	21	22
PBXN-109	0	0.00	0.00	0.00
TNAZ/Al	-15.75	0.00	15.75	0.00
Asphalt	-18.315	0.00	18.32	0.00
Bomb Case	0	0.00	0.00	0.00
Potting	0	0.00	0.00	0.00
Felt Pad	0	0.00	0.00	0.00
Thermal Insulation	0	0.00	0.00	0.00
TCA (solvent)	0	0.00	0.00	0.00
Water	0	(46.00)	0.70	(46.70)
Steam	0	0.00	0.00	0.00
Fuel	0	0.00	0.00	0.00
Air	0	0.00	0.00	0.00
Electricity, kwh/bomb	0	0.00	0.00	0.00
Activated Carbon	0	0.00	0.00	0.00
CO	0	0.00	0.00	0.00
N2	0	0.00	0.00	0.00
H2O	0	0.00	0.00	0.00
H2	0	0.00	0.00	0.00
CO2	0	0.00	0.00	0.00

H	0	0.00	0.00	0.00
HO	0	0.00	0.00	0.00
NO	0	0.00	0.00	0.00
Al	0	0.00	0.00	0.00
O	0	0.00	0.00	0.00
CH4	0	0.00	0.00	0.00
NH3	0	0.00	0.00	0.00
C2H4	0	0.00	0.00	0.00
C3H6	0	0.00	0.00	0.00
C2H6	0	0.00	0.00	0.00
C2H2	0	0.00	0.00	0.00
C3H8	0	0.00	0.00	0.00
CHN	0	0.00	0.00	0.00
C	0	0.00	0.00	0.00
Flue Gas	0	0.00	0.00	0.00
Total gaseous pollutant	0	0.00	0.00	0.00
Al2O3	0	0.00	0.00	0.00
Ash	0	0.00	0.00	0.00

			Burning Ground			Solid	Air
	21	23	24	25	27	Waste	Emissions
PBXN-109	0	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	-15.75	0.00	0.00	0.00	0.00	0	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0
Water	-0.695204082	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?		0.00	0.00 ?		0 ?	
Air	0	0.00 ?		0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0

CO	0	0.00	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00 ?		0.00 ?		0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0.00	0	0

	19	26	Flashing 28	29	30	31	Air Emissions	Solid Waste	Recycle
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Asphalt	-0.185	0.00	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	1,390.00	0	0	0
Potting	-3	0.00	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0	0	0

Fuel	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Air	0	0.00 ?		0.00	0.00	0.00 ?		0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
N2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
H2O	0	0.00	0.00	0.00	0.00	0.00	0	0	0
H2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CO2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
H	0	0.00	0.00	0.00	0.00	0.00	0	0	0
HO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
NO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Al	0	0.00	0.00	0.00	0.00	0.00	0	0	0
O	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Flue Gas	0	0.00	0.00 ?		0.00	0.00	0 ?		0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0	0	0

TABLE 4. INVENTORY FOR OPTION 3 TNAZ DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

	1	2	3	4	4A	5	6	7	Air Emissions	wastewater Emissions
PBXN-109	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	(525.00)	0.00	0.00	525.00	0.00	0.00	0.00	0.00	0	0
Asphalt	(18.50)	0.00	0.00	18.32	0.00	0.00	0.00	0.18	0	0
Bomb Case	(1,390.00)	0.00	0.00	0.00	0.00	0.00	0.00	1,390.00	0	0
Potting	(3.00)	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0	0
Felt Pad	?	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	(25.00)	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0	0
TCA (solvent)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Water	0.00	0.00	(1,296.00)	0.00	0.00	1,296.00	0.00	0.00	0	0
Steam	0.00	(981.00)	0.00	0.00	327.00	0.00	654.00	0.00	327	654
Fuel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Air	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
N2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
HO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
NO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Al	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C2H4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C3H6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C2H6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C2H2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C3H8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
CHN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0

Flue Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Al2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0

		Solidification		
	4	8	9	10
PBXN-109	0	0.00	0.00	0.00
TNAZ/Al	-525	0.00	525.00	0.00
Asphalt	-18.315	0.00	18.32	0.00
Bomb Case	0	0.00	0.00	0.00
Potting	0	0.00	0.00	0.00
Felt Pad	0	0.00	0.00	0.00
Thermal Insulation	0	0.00	0.00	0.00
TCA (solvent)	0	0.00	0.00	0.00
Water	0	(2,284.00)	11.09	(2,295.09)
Steam	0	0.00	0.00	0.00
Fuel	0	0.00	0.00	0.00
Air	0	0.00	0.00	0.00
Electricity, kwh/bomb	0	0.00	0.00	0.00
Activated Carbon	0	0.00	0.00	0.00
CO	0	0.00	0.00	0.00
N2	0	0.00	0.00	0.00
H2O	0	0.00	0.00	0.00
H2	0	0.00	0.00	0.00
CO2	0	0.00	0.00	0.00
H	0	0.00	0.00	0.00
HO	0	0.00	0.00	0.00
NO	0	0.00	0.00	0.00
Al	0	0.00	0.00	0.00
O	0	0.00	0.00	0.00
CH4	0	0.00	0.00	0.00
NH3	0	0.00	0.00	0.00
C2H4	0	0.00	0.00	0.00
C3H6	0	0.00	0.00	0.00
C2H6	0	0.00	0.00	0.00

C2H2	0	0.00	0.00	0.00
C3H8	0	0.00	0.00	0.00
CHN	0	0.00	0.00	0.00
C	0	0.00	0.00	0.00
Flue Gas	0	0.00	0.00	0.00
Total gaseous pollutant	0	0.00	0.00	0.00
Al2O3	0	0.00	0.00	0.00
Ash	0	0.00	0.00	0.00

		Wastewater Treament				Solid	Wastewater
	5	10	11	12	13	Waste	Emissions
PBXN-109	0	0	0.00	0.00	0.00	0	0
TNAZ/Al	0	0	0.00	0.00	0.00	0	0
Asphalt	0	0	0.00	0.00	0.00	0	0
Bomb Case	0	0	0.00	0.00	0.00	0	0
Potting	0	0	0.00	0.00	0.00	0	0
Felt Pad	0	0	0.00	0.00	0.00	0	0
Thermal Insulation	0	0	0.00	0.00	0.00	0	0
TCA (solvent)	0	0	0.00	0.00	0.00	0	0
Water	-1296	2295.08806	0.00	(0.03)	(999.06)	-0.027379407	-999.06068
Steam	0	0	0.00	0.00	0.00	0	0
Fuel	0	0	0.00	0.00	0.00	0	0
Air	0	0	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0	0.00	0.00	0.00	0	0
Activated Carbon	0	0	(0.52)	(0.52)	0.00	-0.520208724	0
CO	0	0	0.00	0.00	0.00	0	0
N2	0	0	0.00	0.00	0.00	0	0
H2O	0	0	0.00	0.00	0.00	0	0
H2	0	0	0.00	0.00	0.00	0	0
CO2	0	0	0.00	0.00	0.00	0	0
H	0	0	0.00	0.00	0.00	0	0
HO	0	0	0.00	0.00	0.00	0	0
NO	0	0	0.00	0.00	0.00	0	0
Al	0	0	0.00	0.00	0.00	0	0
O	0	0	0.00	0.00	0.00	0	0
CH4	0	0	0.00	0.00	0.00	0	0

NH3	0	0	0.00	0.00	0.00	0	0
C2H4	0	0	0.00	0.00	0.00	0	0
C3H6	0	0	0.00	0.00	0.00	0	0
C2H6	0	0	0.00	0.00	0.00	0	0
C2H2	0	0	0.00	0.00	0.00	0	0
C3H8	0	0	0.00	0.00	0.00	0	0
CHN	0	0	0.00	0.00	0.00	0	0
C	0	0	0.00	0.00	0.00	0	0
Flue Gas	0	0	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0	0.00	0.00	0.00	0	0
Al2O3	0	0	0.00	0.00	0.00	0	0
Ash	0	0	0.00	0.00	0.00	0	0

				Flashing			Air	Solid	
	7	14	15	16	17	18	Emissions	Wastes	Recycle
PBXN-109	0	0.00	0.00	0.00	0.00	0.00	0	0	0
TNAZ/Al	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Asphalt	-0.185	0.00	0.00	0.00	0.00	0.00	0	0	0
Bomb Case	-1390	0.00	0.00	0.00	0.00	1,390.00	0	0	1390
Potting	-3	0.00	0.00	0.00	0.00	0.00	0	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Thermal Insulation	-25	0.00	0.00	0.00	0.00	0.00	0	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Water	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Steam	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Fuel	0 ?		0.00	0.00	0.00	0.00	0	0	0
Air	0	0.00 ?		0.00	0.00	0.00	0	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
N2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
H2O	0	0.00	0.00	0.00	0.00	0.00	0	0	0
H2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CO2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
H	0	0.00	0.00	0.00	0.00	0.00	0	0	0
HO	0	0.00	0.00	0.00	0.00	0.00	0	0	0

NO	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Al	0	0.00	0.00	0.00	0.00	0.00	0	0	0
O	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CH4	0	0.00	0.00	0.00	0.00	0.00	0	0	0
NH3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H4	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C3H6	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H6	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C2H2	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C3H8	0	0.00	0.00	0.00	0.00	0.00	0	0	0
CHN	0	0.00	0.00	0.00	0.00	0.00	0	0	0
C	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Al2O3	0	0.00	0.00	0.00	0.00	0.00	0	0	0
Ash	0	0.00	0.00	0.00	0.00	0.00	0	0	0

				Burning Ground		Air	Solid
	9	19	20	21	22	Emissions	Waste
PBXN-109	0	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	-525	0.00	0.00	0.00	0.00	0	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0
Water	-11.0880612	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?		0.00	0.00	0.00	0	0
Air	0	0.00 ?		0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00	179.55	0.00	179.55	0
N2	0	0.00	0.00	122.48	0.00	122.48	0

H2O	0	0.00	0.00	9.92	0.00	9.92	0
H2	0	0.00	0.00	7.14	0.00	7.14	0
CO2	0	0.00	0.00	6.51	0.00	6.51	0
H	0	0.00	0.00	0.52	0.00	0.52	0
HO	0	0.00	0.00	0.36	0.00	0.36	0
NO	0	0.00	0.00	0.05	0.00	0.05	0
Al	0	0.00	0.00	0.05	0.00	0.05	0
O	0	0.00	0.00	0.05	0.00	0.05	0
CH4	0	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	198.24	0	198.24
Ash	0	0.00	0.00	0.00	198.24	0	198.24

			HE/Asphalt Melting			Wastewater
	9	23	24	25	26	Emissions
PBXN-109	0	0.00	0.00	0.00	0.00	0
TNAZ/Al	-525	0.00	0.00	0.19	524.82	0
Asphalt	-18.315	0.00	0.00	18.32	0.00	0
Bomb Case	0	0.00	0.00	0.00	0.00	0
Potting	0	0.00	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0.00	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0
Water	-11.0880612	0.00	162.00	0.00	0.00	162
Steam	0	(162.00)	0.00	0.00	0.00	0
Fuel	0	0.00	0.00	0.00	0.00	0
Air	0	0.00	0.00	0.00	0.00	0

Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0
CO	0	0.00	0.00	0.00	0.00	0
N2	0	0.00	0.00	0.00	0.00	0
H2O	0	0.00	0.00	0.00	0.00	0
H2	0	0.00	0.00	0.00	0.00	0
CO2	0	0.00	0.00	0.00	0.00	0
H	0	0.00	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0.00	0
CH4	0	0.00	0.00	0.00	0.00	0
NH3	0	0.00	0.00	0.00	0.00	0
C2H4	0	0.00	0.00	0.00	0.00	0
C3H6	0	0.00	0.00	0.00	0.00	0
C2H6	0	0.00	0.00	0.00	0.00	0
C2H2	0	0.00	0.00	0.00	0.00	0
C3H8	0	0.00	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0
Al2O3	0	0.00	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0.00	0

			Solidification		
	26	27	28	29	Recycle
PBXN-109	0	0.00	0.00	0.00	0
TNAZ/Al	-524.815	0.00	0.19	0.00	0.185
Asphalt	0	0.00	18.32	0.00	18.315
Bomb Case	0	0.00	0.00	0.00	0
Potting	0	0.00	0.00	0.00	0
Felt Pad	0	0.00	0.00	0.00	0
Thermal Insulation	0	0.00	0.00	0.00	0
TCA (solvent)	0	0.00	0.00	0.00	0
Water	0	1,155.00	0.38	1,154.62	0.37755102

Steam	0	0.00	0.00	0.00	0
Fuel	0	0.00	0.00	0.00	0
Air	0	0.00	0.00	0.00	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0
Activated Carbon	0	0.00	0.00	0.00	0
CO	0	0.00	0.00	0.00	0
N_2	0	0.00	0.00	0.00	0
H_2O	0	0.00	0.00	0.00	0
H_2	0	0.00	0.00	0.00	0
CO_2	0	0.00	0.00	0.00	0
H	0	0.00	0.00	0.00	0
HO	0	0.00	0.00	0.00	0
NO	0	0.00	0.00	0.00	0
Al	0	0.00	0.00	0.00	0
O	0	0.00	0.00	0.00	0
CH_4	0	0.00	0.00	0.00	0
NH_3	0	0.00	0.00	0.00	0
C_2H_4	0	0.00	0.00	0.00	0
C_3H_6	0	0.00	0.00	0.00	0
C_2H_6	0	0.00	0.00	0.00	0
C_2H_2	0	0.00	0.00	0.00	0
C_3H_8	0	0.00	0.00	0.00	0
CHN	0	0.00	0.00	0.00	0
C	0	0.00	0.00	0.00	0
Flue Gas	0	0.00	0.00	0.00	0
Total gaseous pollutant	0	0.00	0.00	0.00	0
Al_2O_3	0	0.00	0.00	0.00	0
Ash	0	0.00	0.00	0.00	0

	Wastewater Treatment				Solid	Wastewater
	29	30	31	32	Waste	Emissions
PBXN-109	0	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0
Asphalt	0	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0	0

Felt Pad	0	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0	0
Water	-1154.62245	0.00	(0.01)	1,154.64	-0.01377415	1154.636223
Steam	0	0.00	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0
Activated Carbon	0	(0.26)	0.26	0.00	0.261708769	0
CO	0	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0	0

		Solidification		
	25	33	34	35
PBXN-109	0	0.00	0.00	0.00
TNAZ/Al	-0.185	0.00	0.19	0.00

Asphalt	-18.315	0.00	18.32	0.00
Bomb Case	0	0.00	0.00	0.00
Potting	0	0.00	0.00	0.00
Felt Pad	0	0.00	0.00	0.00
Thermal Insulation	0	0.00	0.00	0.00
TCA (solvent)	0	0.00	0.00	0.00
Water	0	(39.00)	0.19	38.81
Steam	0	0.00	0.00	0.00
Fuel	0	0.00	0.00	0.00
Air	0	0.00	0.00	0.00
Electricity, kwh/bomb	0	0.00	0.00	0.00
Activated Carbon	0	0.00	0.00	0.00
CO	0	0.00	0.00	0.00
N2	0	0.00	0.00	0.00
H2O	0	0.00	0.00	0.00
H2	0	0.00	0.00	0.00
CO2	0	0.00	0.00	0.00
H	0	0.00	0.00	0.00
HO	0	0.00	0.00	0.00
NO	0	0.00	0.00	0.00
Al	0	0.00	0.00	0.00
O	0	0.00	0.00	0.00
CH4	0	0.00	0.00	0.00
NH3	0	0.00	0.00	0.00
C2H4	0	0.00	0.00	0.00
C3H6	0	0.00	0.00	0.00
C2H6	0	0.00	0.00	0.00
C2H2	0	0.00	0.00	0.00
C3H8	0	0.00	0.00	0.00
CHN	0	0.00	0.00	0.00
C	0	0.00	0.00	0.00
Flue Gas	0	0.00	0.00	0.00
Total gaseous pollutant	0	0.00	0.00	0.00
Al2O3	0	0.00	0.00	0.00
Ash	0	0.00	0.00	0.00

Solid Wastewater

	35	36	37	38	Waste	Emissions
PBXN-109	0	0.00	0.00	0.00	0	0
TNAZ/Al	0	0.00	0.00	0.00	0	0
Asphalt	0	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0	0
Water	-38.8131313	0.00	38.81	0.00	38.81313131	0
Steam	0	0.00	0.00	0.00	0	0
Fuel	0	0.00	0.00	0.00	0	0
Air	0	0.00	0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0	0
Activated Carbon	0	(0.01)	0.01	0.00	0.008797453	0
CO	0	0.00	0.00	0.00	0	0
N2	0	0.00	0.00	0.00	0	0
H2O	0	0.00	0.00	0.00	0	0
H2	0	0.00	0.00	0.00	0	0
CO2	0	0.00	0.00	0.00	0	0
H	0	0.00	0.00	0.00	0	0
HO	0	0.00	0.00	0.00	0	0
NO	0	0.00	0.00	0.00	0	0
Al	0	0.00	0.00	0.00	0	0
O	0	0.00	0.00	0.00	0	0
CH4	0	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0	0
C	0	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0	0
Ash	0	0.00	0.00	0.00	0	0

	34	39	40	41	42	Air Emissions	Solid Waste
PBXN-109	0	0.00	0.00	0.00	0.00	0	0
TNAZ/Al	-0.185	0.00	0.00	0.00	0.00	0	0
Asphalt	-18.315	0.00	0.00	0.00	0.00	0	0
Bomb Case	0	0.00	0.00	0.00	0.00	0	0
Potting	0	0.00	0.00	0.00	0.00	0	0
Felt Pad	0	0.00	0.00	0.00	0.00	0	0
Thermal Insulation	0	0.00	0.00	0.00	0.00	0	0
TCA (solvent)	0	0.00	0.00	0.00	0.00	0	0
Water	-0.18686869	0.00	0.00	0.00	0.00	0	0
Steam	0	0.00	0.00	0.00	0.00	0	0
Fuel	0 ?		0.00	0.00	0.00	0	0
Air	0	0.00 ?		0.00	0.00	0	0
Electricity, kwh/bomb	0	0.00	0.00	0.00	0.00	0	0
Activated Carbon	0	0.00	0.00	0.00	0.00	0	0
CO	0	0.00	0.00	0.06	0.00	0.06327	0
N2	0	0.00	0.00	0.04	0.00	0.043159619	0
H2O	0	0.00	0.00	0.00	0.00	0.003495619	0
H2	0	0.00	0.00	0.00	0.00	0.002516	0
CO2	0	0.00	0.00	0.00	0.00	0.002294	0
H	0	0.00	0.00	0.00	0.00	0.000183238	0
HO	0	0.00	0.00	0.00	0.00	0.000126857	0
NO	0	0.00	0.00	0.00	0.00	1.7619E-05	0
Al	0	0.00	0.00	0.00	0.00	1.7619E-05	0
O	0	0.00	0.00	0.00	0.00	1.7619E-05	0
CH4	0	0.00	0.00	0.00	0.00	0	0
NH3	0	0.00	0.00	0.00	0.00	0	0
C2H4	0	0.00	0.00	0.00	0.00	0	0
C3H6	0	0.00	0.00	0.00	0.00	0	0
C2H6	0	0.00	0.00	0.00	0.00	0	0
C2H2	0	0.00	0.00	0.00	0.00	0	0
C3H8	0	0.00	0.00	0.00	0.00	0	0
CHN	0	0.00	0.00	0.00	0.00	0	0

C	0	0.00	0.00	0.00	0.00	0	0
Flue Gas	0	0.00	0.00	0.00	0.00	0	0
Total gaseous pollutant	0	0.00	0.00	0.00	0.00	0	0
Al2O3	0	0.00	0.00	0.00	0.07	0	0.069856
Ash	0	0.00	0.00	0.00	0.07	0	0.069856

Natural gas

mol%	Mwt	heat value MJ/M^3	Rio Arriba,	Terrell, Tex	Stanton, Ka	San Juan, N	Olds Field,	Cliffside, Texas		avg	SD (rel)
Methane	16.043	37.57	96.91	45.64	67.56	77.28	52.34	65.8			
ethane	30.07	65.83	1.33	0.21	6.23	11.18	0.41	3.8			
propane	44.097	93.6	0.19		3.18	5.83	0.14	1.7			
butane	58.123	120.98	0.05		1.42	2.34	0.16	0.8			
pentane+	72.15	148.84	0.02		0.04	1.18	0.41	0.5			
CO2	44.01	0	0.82	53.93	0.07	0.8	8.22				
H2S	34.076	23.7		0.01			35.79				
N2	28.013	0	0.68	0.21	21.14	1.39	2.53	25.6		avg	SD (rel)
Mol wt:			16.62585	31.182	20.92126	21.28362	25.49289	20.44567		19.61024	10.79%
heating valu	MJ/M^3		37.6	17.3	34.9	46.8	30	30.7		39.76667	12.81%
	MJ/KG		50.65847	12.42768	37.36678	49.25478	26.36029	33.63451		45.76001	13.03%
	0.0224M^3/mol			too high CO2 content for use			too high Sulfur content	too low heating value(?)			

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1984)
averaged from table 9-14

Btu/scf 1049.571

Synopsis of table 9-14

mol%	Mwt	heat value MJ/M^3	Baltimore Md	Columbus Ohio	Houston Tx	Burmingham Al	Washington DC	Phoenix Az		avg	SD (rel)
Methane	16.043	37.57	94.4	93.14	92.5	93.14	95.15	87.37			
ethane	30.07	65.83	3.4	3.58	4.8	2.5	2.84	8.11			
propane	44.097	93.6	0.6	0.66	2	0.67	0.63	2.26			
butane	58.123	120.98	0.5	0.22	0.3	0.32	0.24	0.13			
pentane+	72.15	148.84	0	0.09	0	0.12	0.05	0			
CO2	44.01	0	0.6	0.85	0.27	1.06	0.62	0.61			
H2S	34.076	23.7		0.01							
N2	28.013	0	0.5	0.21	21.14	2.14	0.42	1.37		avg	SD (rel)
Mol wt:			17.12629	16.93912	23.38022	17.32821	16.9628	18.17984		18.31941	15.84%
heating valu	MJ/M^3		39.2023	38.3444	38.4563	38.1952	38.8666	39.9483		38.83552	1.10%
	MJ/KG		51.27388	50.70597	36.84401	49.37455	51.32477	49.22167		48.12414	13.30%

0.0224M^3/mol

anufactured gas

ata from KO 2 (1964) for "modern mechanical method"				Gas			gas heat value				Tar data	
	Moisture	Heating valueBtu/lb		Gas yield scf/ton		gas lb/lb co	Gross heat value Btu/s		Btu/ton coa	Btu/lb coal	Tar yield gal/ton	
		wet	dry	wet base	dry base		wet base	dry base	wet base	wet base	wet base	dry base
nthracite	0.051	10800	11380.4	123900	130558.5		138	145.4162	17098200	8549.1	9.5	10.01054
elgian Co	0.026	11980	12299.79	120900	124127.3		150	154.0041	18135000	9067.5	1	1.026694
addesley	0.05	12080	12715.79	116100	122210.5	3.581182	165.6	174.3158	19226160	9613.08	21	22.10526

On the basis of 10% tar production in the process the Baddesley type coal is used

This coal then provides 9613.08 gas heating value in Btu/lb coal

addesley coal ga

ompositior	MWt	vol%	O2 per mol	mol O2 per mol gas			
O2	44.01	6.7	0	0			
lkyls							
2	31.9988	0	0	0			
O	28.016	25.3	0.5	0.1265			
2	2.0158	21	0.5	0.105			
H4	16.043	1.8	2	0.036			
2	28.013	45.2	0	0		0.578864	mol air producing mol gas
as Mwt	23.41069			0.2675	mol O2 per mol gas	1.277093	mol air to burn mol gas
				0.365631	kg O2 per Kg gas	1.855957	mol air used/mol gas
leal gas density of producer gas				1.580041	kgair/kg gas	2.296221	kg air used / kg gas
0.9882	kg/m^3						
.061691	lb/s cuf			d=Mw/0.0224			

hysical data

ensity of T	75	lb/cuf	Perry 6 (1984)
	1200	kg/m^3	
	10.01449	lb/gal	

nits

cf is volume in cubic feet at 60 Farenheit and 30" Hg — KO 2 (1964)

288.7056 42.2115 0.02369

ensity	lb/cuf	lb/gal	kg/m^3		Perry 6 (1984)
	0.062428	0.008345	1		
	7.480519	1	119.8264		
	1	0.133681	16.01846		

hass	ton (short -	lb	kg		Perry 6 (1984)
	1	2000			
		2.204623	1		

ressure	"Hg	N/m^2	atm	psia	Perry 6 (1984)
	1	3376.9	0.033327	0.489775	
	2.041754	6894.8	0.068046	1	
	30.00533	101325	1	14.69586	
		1			

leat value	MJ/m^3	btu/scf	Perry 6 (1984)
	0.0373	1	

nergy	MJ	Btu	Perry 6 (1984) for steam table values
	0.001055	1	

dry air composition	molar	Mwt	mass comp	kg air per kg component
N2	0.78084	28.0134	0.75521	1.324134
O2	0.20946	31.9988	0.231406	4.321406
CO2	0.00033	44.01	0.000501	1994.319
Ar	0.00934	39.948	0.012882	77.62792
total	0.99997	28.96409	1	

Coal type	Moisture	Sulfur		Heat value				
	%	%	%dry	Btu/lb	Btu/lbdry			
Sub bit C	26	0.3	0.41	8230	11121.62			
HV bit A	2.9	0.6	0.62	14170	14593.2	low sulfur coal heating value		
Sub bit B	22.2	0.5	0.64	9610	12352.19			
Brown Coa German - R	55	0.3	0.67	4830	10733.33			
Sub bit A	13.9	0.6	0.70	10330	11997.68	SD=	1295.775	0.108169
Meta Anthracite	9	0.7	0.77	10080	11076.92	Avg=	11979.16	
LV bit	2.9	0.8	0.82	14400	14830.07	median		
Anthracite	4.3	0.8	0.84	12880	13458.73		27.86352	MJ/kg
Lignite	36.8	0.9	1.42	7000	11075.95		dry base	
MV bit	2.4	1.5	1.54	14490	14846.31			
Semi anthracite	2.1	1.7	1.74	13700	13993.87			
HV bit B	6.7	2.6	2.79	12390	13279.74			
HV bit C	15.4	2.9	3.43	10740	12695.04			

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949